Impact Area Groundwater Study Program

DRAFT

J-2 Range North Groundwater Rapid Response Action (RRA) Plan

Camp Edwards
Massachusetts Military Reservation
Cape Cod, Massachusetts

April 26, 2005

Prepared for:

U.S. Army Corps of Engineers
New England District
Concord, Massachusetts
for
U.S. Army / National Guard Bureau
Impact Area Groundwater Study Program
Camp Edwards, Massachusetts

Prepared by:

ECC
Contract No. DACW33-02-D-0003, CTO 002

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DISCLAIMER

This document has been prepared pursuant to government administrative orders (U.S. EPA Region 1 SDWA Docket No. I-97-1019 and 1-2000-0014) and is subject to approval by the U.S. Environmental Protection Agency. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Environmental Protection Agency.

NOTICE

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DRAFT

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CERTIFICATION:

I hereby certify that the enclosed J-2 Range North Groundwater Rapid Response Action (RRA) Plan, shown and marked in this submittal, is that proposed to be incorporated with Contract Number DACW33-02-D-0003, Contract Task Order 002. This Plan has been prepared in accordance with USACE Scope of Work and is hereby submitted for Government approval.

Reviewed by:

04/26/05

Contractor Quality System Manager — Date

4/26/05

ECC Project Manager — Date

4/26/05

ECC Program Manager — Date

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USACE Project Manager — Date

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ACRONYMS AND ABBREVIATIONS

2A-DNT	2-amino-4,6-dinitrotoluene
3D	three-dimensional
4A-DNT	4-amino-2,6-dinitrotoluene
AFCEE	Air Force Center for Environmental Excellence
AO	Administrative Order
ASR	Archive Search Report
BBM	Buzzards Bay Moraine
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980 (Superfund)
CFR	Code of Federal Regulations
CMR	Commonwealth of Massachusetts Regulation
COC	contaminant of concern
cy	cubic yard
DWEL	drinking water equivalent level
EPA	U.S. Environmental Protection Agency
ETI	extraction, treatment, and infiltration
ft.	feet
GAC	granular activated carbon
GMS	groundwater modeling system
gpm	gallons per minute
HA	Health Advisory
HDPE	high-density polyethylene
HMX	octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
IAGWSP	Impact Area Groundwater Study Program
IRP	Installation Restoration Program
IX	ion-exchange
Jacobs	Jacobs Engineering
K	hydraulic conductivity
kg	kilograms
LTGM	Long Term Groundwater Monitoring
MADEP	Massachusetts Department of Environmental Protection

MCL	maximum contaminant level
MEC	munitions and explosives of concern
mgd	million gallons per day
MMCL	Massachusetts maximum contaminant level
mL/g	milliliter per gram
MMR	Massachusetts Military Reservation
MPP	Mashpee Pitted Plain
msl	mean sea level
MSP	Munitions Survey Project
O&M	operations and maintenance
PEP	pyrotechnic, explosives and propellant
PPE	personal protective equipment
PRG	preliminary remediation goals
RAO	remedial action objectives
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine
Rf	retardation factor
RfD	reference dose
RRA	rapid response action
SDWA	Safe Drinking Water Act of 1974
SE	Southeast
SM	Sandwich Moraine
SPEIM	system performance and ecological impact monitoring
TERC	Total Environmental Restoration Contract
TNT	trinitrotoluene
TOM	top of mound
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
ZOC	zone of contribution
µg/L	micrograms per liter

EXECUTIVE SUMMARY

This *Draft J-2 Range North Groundwater Rapid Response Action (RRA) Plan* presents the assessment activities, modeling, and wellfield design proposed by the Impact Area Groundwater Study Program (IAGWSP) to address the J-2 North plume. Controlling migration of the J-2 North plume is an important consideration for the RRA as public water supply well WS-2 is situated downgradient of the perchlorate contamination. Contaminant mass removal (both hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX] and perchlorate) is also a goal for the RRA as focused mass removal will serve to accelerate plume remediation and shorten the timeframe for aquifer restoration.

This work has been conducted by the U.S. Army Corps of Engineers (USACE) under the Total Environmental Restoration Contract (TERC) DACW33-02-D-003, contract task order CTO-02 in support of the IAGWSP, pursuant to U.S. Environmental Protection Agency (EPA) Administrative Orders (AOs) under the Safe Drinking Water Act of 1974 (SDWA).

This RRA plan includes:

- a summary of results of ongoing investigations and evaluations;
- a summary of wellfield design modeling (including determination of pumping rate requirements, flow rate distribution and screen length, and treated water infiltration requirements);
- identification of design criteria;
- regulatory considerations; and,
- RRA schedule considerations.

The J-2 North plume is located on the eastern portion of the Massachusetts Military Reservation (MMR) Impact Area at Camp Edwards. This plume consists primarily of perchlorate and RDX, which are migrating in a northerly direction toward the Upper Cape Water Supply Cooperative supply well WS-2 (Figure 1-3 and Figure 1-4). The maximum concentrations of perchlorate and RDX detected in monitoring wells in the plume to date are 140 micrograms per liter (µg/L) and 11 µg/L, respectively. No known private or public supply wells have been impacted by the J-2 North plume. The primary source area for the J-2 North plume is Disposal Area 2, located on the northwest portion of the J-2 Range (Figure 1-

2). In 2004, approximately 400 cubic yards of contaminated soil was removed from Disposal Area 2 in conjunction with the J-2 Soil RRA activities.

The Southeast (SE) Ranges flow and transport model and three-dimensional (3D) plume shells for RDX and perchlorate were updated based on recent groundwater investigation data. Transport simulations were conducted to evaluate the model-predicted trajectory of the RDX and perchlorate plumes and to determine an appropriate wellfield strategy to remediate the J-2 North plume.

The J-2 North wellfield scenario testing results and constructability review indicate that the most efficient wellfield design includes: three extraction wells (J2EW0001, J2EW0002, and J2EW0003) oriented along the plume axis and operating at 75, 175, and 125 gallons per minute (gpm) respectively; four identical modular treatment units capable of handling 100 gpm of water a piece, and four infiltration trenches to return treated groundwater to the aquifer (Figure 5-23). Extraction well J2EW0001 will be located approximately 550 feet (ft.) south of the intersection of Wood Road and Barlow Road, J2EW0002 will be located along Barlow Road approximately 900 ft. north of the intersection of Wood Road and Jefferson Road, and J2EW0003 will be located approximately 600 feet north of the intersection of Barlow Road and Jefferson Road. The treatment units will be located at the intersection of Wood Road and Barlow Road.

The proposed treatment train (granular activated carbon, ion-exchange, and polishing granular activated carbon [GAC-IX-GAC]) (Figure 5-24) is consistent with the technology currently employed at the Frank Perkins Road treatment plant on MMR and planned for the J-3 Groundwater RRA to address identical contaminants of concern (COCs) as those found in the J-2 North plume. GAC adsorption for RDX removal, IX resin for perchlorate removal, and a polishing GAC in the event of breakthrough is anticipated to reduce contaminant concentrations to required treatment levels. The performance of these media is documented in several reports, results of which demonstrate that these treatment technologies are appropriate for the removal of perchlorate and RDX from groundwater. After passing through the pretreatment filter and the GAC-IX-GAC train, the treated water will be reintroduced to the groundwater through infiltration trenches. The trenches are to be located along existing roads. Two are to be situated along Wood Road and two along Jefferson Road.

The modeling results indicate the final RRA design 1) controls plume migration, 2) actively addresses the zone of highest RDX and perchlorate contamination, 3) captures 92.7 percent of the perchlorate and 91 percent of the RDX, 4) remediates the aquifer in a reasonable time frame (reduces RDX below the Lifetime Health Advisory [HA] in approximately seven years), and 5) is protective of water supply well WS-2 which provides drinking water to the Upper Cape Water Supply Cooperative. The maximum modeled influent concentrations of RDX and perchlorate in water supply well WS-2, with the proposed treatment system operating, are 0.000035 µg/L and 0.031 µg/L, respectively.

Because of the proximity of the proposed J-2 North pumping to the J-1 and J-2 East plumes, an evaluation of potential impacts on these plumes' trajectories was assessed by evaluating the model-predicted drawdown and mounding under stressed conditions reflective of the wellfield design pumping stress. The extent of the model-predicted hydraulic influence indicates that the pumping stress at J-2 North is not sufficient to detrimentally affect the J-1 or J-2 East plumes (Figure 5-13).

No sensitive surface water bodies were identified in the vicinity of the J-2 North plume, and therefore, no assessment of ecological thresholds (e.g., drawdown, changes in flux, etc.) was necessary.

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1.0 INTRODUCTION

The Impact Area Groundwater Study Program (IAGWSP) with support from the U.S. Army Corps of Engineers (USACE) is conducting investigations to assess soil and groundwater contamination resulting from the historical land uses at the Camp Edwards Impact Area and training ranges. This document identifies and evaluates characteristics of the J-2 North plume and the proposed rapid response action (RRA) to mitigate further migration of the plume. Activities necessary to complete the conceptual design of the proposed RRA system are also included as part of this RRA plan.

The Massachusetts Military Reservation (MMR) is located on upper Cape Cod, approximately 60 miles south-southeast of Boston. Approximately 15,000 acres of this 22,000-acre facility, referred to as the range, maneuver and Impact Area, have been used for military and law enforcement training (Figure 1-1). For over 46 years, the Camp Edwards training ranges and Impact Area have been used for training military and law enforcement in the use of small arms, mortars, heavy artillery, and ordnance demolition. In some areas, the spent shells and byproducts of the used munitions have resulted in environmental degradation of the soil and groundwater.

The J-2 Range, which is the northernmost of the four former training ranges that comprise the Southeast (SE) Ranges near the eastern border of the MMR, was used by both military contractors for testing and development of various weapons and systems, and by the military for training purposes. The J-2 North plume consists primarily of perchlorate and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and is believed to originate near Disposal Area 2 located on the northwestern portion of the J-2 Range (Figure 1-2). The plume migrates northerly towards Upper Cape Water Supply Cooperative water supply well, WS-2 (Figure 1-3 and Figure 1-4).

Ongoing groundwater investigations have generated sufficient plume characterization and water quality data to assess the viability of implementing an RRA to initiate the cleanup of the J-2 North plume. Accordingly, this document presents the results and recommendations of an evaluation of the feasibility of utilizing various pre-fabricated treatment components to capture and treat the J-2 North plume. The pre-fabricated treatment components are packaged in containers and were developed and proven at other installation areas at MMR (e.g. Frank Perkins Road).

1.1 PURPOSE

The purpose of this RRA plan is to provide details on the IAGWSP's plan to initiate the cleanup of groundwater contamination from the J-2 site while further studies and analyses are ongoing. It includes the results of the evaluation conducted to determine capture requirements and viable treatment components to remove J-2 North plume contaminants and to present a proposed conceptual design to address further J-2 North plume migration. The plan also presents an overview of the schedule for implementation.

1.2 REPORT ORGANIZATION

This report is divided into eight main sections. Section 1.0 is this introduction, which provides the purpose of the RRA plan and an overview of the document. Section 2.0 includes site description, history and ongoing groundwater investigations. Section 3.0 includes a description of the groundwater characteristics and the conceptual site model for the J-2 North plume. Section 4.0 is a review of regulatory considerations. Section 5.0 describes flow and transport model development, contaminant plume shell development and the conceptual wellfield design for the extraction, treatment and infiltration (ETI) system; provides an overview of the groundwater fate and transport simulations conducted for wellfield design, and presents the preliminary basis of design. Section 5.0 also summarizes the proposed treatment train process. Section 6.0 presents the performance monitoring plan requirements for the J-2 North groundwater ETI system. Section 7.0 presents a discussion of key timeframes for schedule consideration. Section 8.0 lists the references cited in this document. The CD provided with this report includes eight animations used to evaluate the effectiveness of various remedial alternatives, and the data used to conduct the risk screening documented in Section 3.1.

2.0 BACKGROUND

Historical site operations, geological and hydrogeological setting and site investigations conducted at J-2 are summarized in this section.

2.1 SITE DESCRIPTION AND HISTORY

MMR is located in the western portion of Cape Cod and occupies approximately 22,000 acres (35 square miles) within the towns of Bourne, Sandwich, Mashpee, and Falmouth in Barnstable County, Massachusetts (Figure 1-1). Military use of portions of the MMR began as early as 1911. Most of the activity, however, has been conducted since 1935 and has included operations by the U.S. Army, U.S. Coast Guard, U.S. Air Force, Massachusetts Army National Guard, U.S. Air National Guard, and Veterans Administration. The level of activity at MMR has varied over its operational history. Some specific activities have resulted in a number of contaminants being released into the environment, including the groundwater.

The SE Ranges are former training and defense contractor test ranges. Most of the activity on the ranges occurred between the 1950s and the 1970s; some activities continued into the late 1980s/early 1990s (AMEC 2001a). Defense contractor activities included open burning and detonation of explosives, disposal of wastewater, and disposal of munitions in burial pits. Military activities conducted in the area of the J-2 Range primarily involved small arms, mortar and grenade training.

The IAGWSP is continuing to investigate the extent of soil and groundwater contamination within and emanating from the SE Ranges. To date, investigations have identified several plumes associated with this area. The plumes vary in composition but are generally a mixture of RDX; HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) and perchlorate.

2.1.1 J-2 Range

The J-2 Range (Figure 1-2) is located adjacent to and southeast of the Impact Area, and is one of the ranges formerly utilized by military contractors for testing and development of various weapons and systems, and by the military for training purposes. The original J-2

Range was established in the late-1940s along the west side of Greenway Road, in the area currently designated as N Range. The J-2 Range has been used historically as a musketry range (1935-1940s), transition range (1940s-1950s), rifle range (1960's-1980's), and a contractor test range (1953-1980) (AMEC 2003b). Examples of activities conducted by various contractors include: propellant and fuze testing, penetration testing for various munitions, fragmentation testing, obscuration testing, infrared testing of tank heat signatures, propellant and waste burning, munitions disposal, and loading of munitions with explosives. Based on various witness interviews, the J-2 Range was also reportedly utilized as an open burn/open detonation area by both military personnel and contractors (AMEC 2003b).

The J-2 Range and immediate downgradient areas are located within the Mashpee Pitted Plain (MPP), which consists of high-permeability sand and gravel deposits. The Impact Area is proximal to the apparent glacier terminus, and therefore, contains the coarsest sand and gravel deposits in the MPP (Masterson et al. 1997). The J-2 Range lies near the top of the Sagamore Lens of the aquifer underlying the upper Cape, and as a result, the water table beneath the range is very flat. This results in low horizontal gradients and relatively steep vertical gradients.

2.1.2 Geology

The surficial geology of western Cape Cod comprises glacial sediments deposited during the retreat of the Wisconsinan stage of continental glaciation. Three extensive sedimentary units characterize the regional geology: the Buzzards Bay Moraine (BBM), the Sandwich Moraine (SM), and the MPP. The BBM and the SM lie along the western and northern edges of western Cape Cod, respectively. The BBM and SM are composed of ablation till, which is poorly sorted material ranging from clay to boulder size that was deposited at the leading and lateral edges of two lobes of the Laurentide ice sheet during a readvance of the ice front. These moraines form hummocky ridges. The MPP, which consists of fine to coarse-grained sands forming a broad outwash plain, lies south and east of the two moraines. Underlying the MPP are fine-grained, glaciolacustrine sediments and basal till. In some areas these units are not evident and the sand of the MPP overlies bedrock.

The J-2 North plume is migrating through very transmissive unconfined sandy glacial outwash deposit. The sandy nature of the surface soils promotes rapid infiltration with little run-off. Discontinuous silty sand or clayey sand units occur sporadically within the saturated zone. The continuity of these fine-grained deposits increases deep within the aquifer and results in localized areas of lower hydraulic conductivities (K) and reduced groundwater velocities that serve to restrain some plume contaminants. In the vicinity of the J-2 Range, it appears the silt units are interbedded with sands; however, the silts do not directly overlie bedrock. North of the J-2 area, the silty lacustrine deposits directly overlie the granodiorite bedrock (Figure 2-1a, Figure 2-1b, Figure 2-2a, Figure 2-2b, Figure 2-3a, Figure 2-3b, Figure 2-4a and Figure 2-4b).

2.1.3 Hydrogeology

A single groundwater flow system underlies western Cape Cod, including MMR. The aquifer system is unconfined (i.e., it is in equilibrium with atmospheric pressure and is recharged by infiltration from precipitation). The high point of the water table occurs as a groundwater mound beneath the southeastern portion of Camp Edwards, immediately south-southwest of the J-2 North plume source area. Groundwater flow generally radiates outward from this mound. The ocean bounds the aquifer on three sides, with groundwater discharging into Nantucket Sound on the south, Buzzards Bay on the west, and Cape Cod Bay on the north. The Bass River in Yarmouth forms the eastern lateral aquifer boundary.

Based on water table measurements and contaminant data, a distinct vertical gradient is distinguishable at wells in the J-2 North plume source area. This indicates notable downward flow near the top of the groundwater mound. Farther downgradient toward the midpoint of the plume, the vertical gradient is reduced. Additional details of aquifer properties are provided in Section 5.1.

2.2 SUMMARY OF INVESTIGATIONS AND RESPONSE ACTIONS

Based on investigations summarized in the following subsections, the principal environmental concerns identified to date associated with the J-2 North plume include the following:

- soils contaminated by explosives and propellants at Disposal Area 2; and,
- a contaminant plume which has been identified as the J-2 North plume, apparently originating at or near Disposal Area 2 on the northwest portion of the J-2 Range. The perchlorate component of this plume has been mapped from its apparent source at Disposal Area 2 north-northeast past Jefferson Road, approximately 7,800 feet downgradient of the J-2 Range (Figure 1-4); the RDX component of this plume has been mapped approximately 4,200 feet downgradient of the J-2 Range (Figure 1-3). Additionally, deeper components of perchlorate and RDX have been observed in monitoring well MW-289; however, this contamination is detached, as the upgradient wells are clean at similar depths and there is no apparent source for this deeper contamination (see Figure 2-1a and Figure 2-1b). Analytical results indicate that the plume is composed principally of two explosives, RDX and HMX, and the propellant perchlorate. Additional information regarding groundwater contamination is presented in the *Final J-2 Range Supplemental Groundwater Workplan* (AMEC 2003b).

2.2.1 Ordnance and Contaminant Investigations

Intensive investigative activities at the J-2 Range commenced in August 2000, and have been conducted in accordance with the following workplans and supplemental investigations.

- *Final J-2 Range Workplan* (OGDEN 2000), August 2000;
- *Final J-2 Range Additional Delineation Workplan No. 1* (AMEC 2001b), June 2001;
- *Final J-2 Range Additional Delineation Workplan No. 2* (AMEC 2002), March 2002;
- *Final J-2 Range Supplemental Groundwater Workplan* (AMEC 2003b), December 2003;
- *Final Revised J-2 Range Supplemental Soil Workplan* (AMEC 2004a), April 2004; and,
- *J-2 Range Supplemental Geophysical Anomaly Investigation Workplan* (ECC 2004), June 2004.

The investigative activities at the SE Ranges are components of a larger investigation program being conducted by the Army as part of the IAGWSP at Camp Edwards. Two other components of the program, the Munitions Survey Project (MSP) and the Archive Search Report (ASR) Project are investigations under which the IAGWSP pursued the discovery and/or exploration of previously unidentified potential source areas within the MMR boundary, including the J-2 Range. Under the MSP, numerous locations with the potential for the presence of munitions and explosives of concern (MEC), buried caches of MEC or MEC-related material, and other scrap have been identified at the J-2 Range. These areas have been identified through air-borne and ground-based geophysical investigations. A total of 35 polygons, comprising certain individual and grouped anomalies, were selected for investigation by inspection and excavation (ECC 2004). These investigation results have identified a wide variety of non-MEC materials as well as MEC-related munitions, grenades, barrage rockets, fuses and other components.

The MSP has identified areas where geophysical surveys identified anomalous magnetic and electromagnetic fields. At other sites, buried munitions, other metallic material, and debris as well as other items of lesser investigative interest such as ferromagnetic rocks and man-made surface features (fences) have been shown to produce similar anomalous geophysical signals of the type observed at the J-2 Range. The areas exhibiting significant geophysical attributes have been located, described, and in some cases excavated and sampled in accordance with the EPA-approved MSP workplan, to characterize location and spatial distribution of potential disposal sites, munitions, debris and related contamination (ECC 2004).

The *Final Revised J-2 Range Supplemental Soil Workplan* (AMEC 2004a) summarizes source area characterization that is ongoing at the time of publication of this RRA plan. The objective of this continuing work is to better characterize known J-2 Range source areas and identify (and delineate) additional potential source areas not previously identified. At this time, the major source resulting in the known J-2 North plume appears to be Disposal Area 2 (Figure 1-2).

2.2.2 Groundwater Study

The characterization of soils from various areas within the J-2 Range is motivated, in part, by the presence of groundwater contamination in the vicinity and downgradient of the J-2 Range. Various areas within the J-2 Range boundaries have been investigated as potential sources of the observed groundwater contamination. Based on the presence of pyrotechnic, explosives and propellant (PEP) compounds in soils, and particle backtracking of downgradient groundwater contamination, Disposal Area 2 is the most likely potential source area for the J-2 North plume. Analytical results indicate that the plume which emanates from the J-2 Range Disposal Area 2 is composed principally of perchlorate and

RDX. As further detailed in Section 3.0 of this report, the perchlorate and RDX lobes of the J-2 North plume both have a deeper component. The depth of these contaminants within the aquifer and reverse particle tracking suggest a source further upgradient than the J-2 Range Disposal Area 2. The data suggest this deeper contamination is detached from its source area (i.e. wells upgradient of this deeper contamination do not contain detectable levels of RDX or perclorate) indicating that its source area has likely stopped contributing to recent groundwater contamination. The identified sources areas are undergoing investigation to determine the nature and extent of soil contamination and their existing or potential contribution to groundwater contamination.

The latest documented characterization of the J-2 North plume is provided in the *Final J-2 Range Supplemental Groundwater Workplan* (AMEC 2003b) and the *Final Revised J-2 Range Supplemental Soil Workplan* (AMEC 2004a). The workplans present interpretation of existing groundwater and soil analytical results and the hydrogeologic modeling conducted for the SE Ranges as of early 2003. The goals of the workplans are to identify data gaps and propose investigative activities to fill those gaps. Activities include the installation and sampling of supplemental groundwater monitoring wells and additional modeling activities to support optimal well placement. Following submission of the draft groundwater workplan, significant improvements to hydraulic and chemical characterization of the J-2 North plume have been made. Much of these new data have been used to update the conceptual model of the plume and the SE Ranges model. These efforts are further described in Section 5.1.

As documented in the supplemental groundwater workplan (AMEC 2003b), 16 wells had been installed at or downgradient of the J-2 Range under previous J-2 Range investigation workplans. Three additional wells (J2P-18, J2P-19 and J2P-20) were recommended as part of the supplemental workplan. Based on findings at J2P-20, 15 additional wells (J2P-29 through J2P-40, and J2P-42 through J2P-44) have been installed and used for plume delineation. At least two additional wells are planned to fill in data gaps in the J-2 Plume ([J2E-14 and J2E-15] [Figure 1-3 and Figure 1-4]). J2E-14 will be installed east of MW-322 to delineate the eastern extent of the J-2 North plume. It is anticipated that this well will aid in defining the upgradient extent of the RDX lobe located around MW-322, and provide information on the eastern extent of the main J-2 North plume lobe. J2E-15 will be located southwest of MW-366 to provide better definition on the degree of separation between the J-2 North plume and the J-2 East plume.

The IAGWSP has completed several modeling tasks pertinent to the J-2 Range study area. Previous modeling efforts have been used to aid in developing the plume conceptual model and more recently to simulate fate and transport. A regional groundwater flow model has been developed for analysis of the impacts of remedial system stress on plume migration and water supply evaluation. In addition, the regional model has been used to assess the characteristics of the top of the water table mound and its influence on flow directions and contaminant migration. This model also provided the boundary conditions for the higher resolution subregional models focused on assessing the SE Ranges plumes. Earlier models, as well as the latest model development, are summarized in Section 5.1.

The conceptual model of the plume will be updated as the upcoming drilling and sampling data are collected, and new plume shells are developed. Verification of plume conceptual model updates will be based on discussions with the EPA and the Massachusetts Department of Environmental Protection (MADEP). This updated information will then be used to confirm or revise the remedy outlined in this plan prior to implementation, and will be used during the groundwater report/feasibility study to assess plume fate and transport and to support final plume response decision-making.

2.2.3 Other Related Investigations

The following sections describe on-going investigations in the vicinity of the J-2 North plume, including the J-2 East plume and the J-1 Range plume, removal actions at the J-2 Range, and the Upper Cape Water Supply Project including public water supply well WS-2. Additional discussion of groundwater modeling investigations related to the Upper Cape Water Supply are included in Section 5.1.4.

2.2.3.1 J-2 East Plume and J-1 Range Plume

The J-2 East plume and the J-1 plume are situated east and west of the J-2 North plume, respectively. Ongoing investigations will complete the determinations of groundwater contaminant nature and extent of these areas. The results of the ongoing investigations will be presented in future groundwater characterization reports. The proximities of the J-2 East plume and the J-1 plume have been considered in the design of the J-2 North RRA wellfield design (See Section 5.1.4).

Recent detection of perchlorate at MW-366 suggest additional groundwater contamination along the northern side of the J-2 Range. The extent of contamination in the vicinity of MW-366 has not yet been determined; however, future well installations (J2E-14 and J2E-15) will provide additional information in this area. The contaminant detections at MW-366 are likely unrelated to Disposal Area 2 (and the J-2 North plume) and should not affect the progress of the J-2 North RRA.

2.2.3.2 J-2 Range Removal Actions

The J-2 Range Soil RRA was implemented to reduce or eliminate potential sources of groundwater contamination within the J-2 Range which were derived from historic training and munitions testing and disposal activities. The general approach of the RRA at the J-2 Range was to excavate soil near site features where existing analytical data indicated the highest levels of explosive or PEP compounds are present.

The J-2 Range Soil RRA activities commenced in May 2004, and continue through the writing of this work plan. To date approximately 6,200 cubic yards (cy) of soil has been MEC cleared, excavated, mechanically screened for MEC, and thermally treated at H Range. All treated soils will be used as backfill materials at Demolition Area 1. All proposed excavation areas, including most of Polygon 2 (the suspected source of the J-2 North plume) and Berm 5 were complete as of 18 March 2005. Excavation activities for Polygon 2 and Berm 5 are scheduled to be completed in June 2005, and are expected to generate an additional 500 cy of soil. These soils will be sent off-site for disposal/treatment.

2.2.3.3 Upper Cape Water Supply Project

The Upper Cape Water Supply Cooperative includes three water supply wells in the northeastern corner of the MMR. Water supply well WS-2 is located downgradient of the J-2 North plume, with water supply wells WS-1 and WS-3 located to the east and west of WS-2, respectively. Supply wells WS-1 and WS-3 are not expected to be impacted by the J-2 North plume.

In 2000, pumping tests were conducted to determine the hydraulic characteristics of the aquifer including the interaction of moraine and outwash sediments (Earth Tech 2000). It was determined that the aquifer was productive; however, the shallow portion of the aquifer was found to contain more fine-grained sediments, with coarse hydraulically conductive sands located deeper in the aquifer. Based on the pumping test results, the well screen for WS-2 was set lower in the aquifer. This information was incorporated into the regional model used for this J-2 North RRA Plan.

WS-2 is screened from approximately -51 to -71 feet mean sea level (msl). The well is permitted at 1.5 million gallons per day (mgd); however, the actual annualized average flow rate is 0.246 mgd. Water supply wells WS-1 and WS-3 operate at similar flow rates as WS-2. Modeling and field data indicate that the J-2 North plume will not migrate into the zone of contribution (ZOCs) to these latter two supply wells.

No contamination associated with the J-2 Range has been detected in any of the current existing monitoring wells or sentry wells for WS-2, located near and north of Gibbs Road.

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3.0 GROUNDWATER CHARACTERIZATION

Contaminants of concern (COCs) as defined in CERCLA have not been formally agreed upon for the J-2 North plume. However, a risk screening evaluation has been conducted to help identify the contaminants to be addressed as part of this RRA. The risk screening was conducted using data available at the time that the Draft J-2 North Groundwater RRA Plan was developed. The results of the risk screening indicate that an RRA to address contaminated groundwater would safeguard beneficial use of the aquifer. This section discusses the nature and extent of the J-2 North plume, the conceptual site model, and presents the results of the risk screening.

3.1 CONTAMINANT NATURE AND EXTENT

Based on available groundwater monitoring well data, the following explosive and propellant compounds have been identified in the J-2 North plume.

- 2,4,6-trinitrotoluene (TNT);
- 2-amino-4,6-dinitrotoluene (2A-DNT);
- 4-amino-2,6-dinitrotoluene (4A-DNT);
- 3-nitrotoluene;
- RDX;
- HMX; and,
- perchlorate.

RDX, HMX and perchlorate are the most prevalent compounds detected and are mappable as a plume. Therefore, only RDX, HMX, and perchlorate were evaluated as part of the risk screening.

Perchlorate originates as a contaminant in the environment from the solid salts of ammonium, potassium, or sodium perchlorate. It is found in munitions, primarily as a component of explosive initiating devices (fuses) or spotting charges, but also occurs as a constituent of the explosive filler in a limited number of munitions. Ammonium and potassium perchlorate are manufactured for use as the oxidizer component and primary ingredient in solid propellant for rockets, missiles, and fireworks, in addition to being used in some delay compositions, flares (including roadside flares), signaling devices, other pyrotechnics, smokes, and tracers.

The presence of the explosive and propellant compounds in groundwater is consistent with the following observations:

- perchlorate is a component of inert munitions, fireworks, rocket propellants and pyrotechnics that were likely disposed of at Disposal Area 2, the suspected origin of the J-2 North plume; and,
- perchlorate, RDX, and HMX were detected in soil at the J-2 Range.

A risk screening was completed to determine whether detected concentrations of RDX, HMX and perchlorate exceed preliminary remediation goals (PRGs). PRGs are risk-based values established by EPA Region 9 for screening concentrations of contaminants in environmental media. The PRGs for RDX, perchlorate and HMX are presented in Table 3-1. Other regulatory criteria for RDX, HMX, and perchlorate are discussed in Section 4.2.

The results of the risk screening are summarized in Table 3-1 and the data are presented in Attachment 3-1. As indicated in the table, the PRG for HMX was not exceeded by any of the detected concentrations in groundwater associated with the J-2 North plume; however, the PRGs for RDX and perchlorate were exceeded 23 and 25 times, respectively. Hence, based on comparison to the PRGs, both RDX and perchlorate are at concentrations in groundwater that may cause adverse effects to humans if consumed as drinking water over a lifetime.

Based on the risk screening, perchlorate and RDX were used as the primary constituents for modeling, treatability assessment, and system design considerations. The RRA itself is being implemented to address RDX, perchlorate, and HMX. A full characterization of groundwater and a determination of associated risk will be provided in a future J-2 North Groundwater Characterization Report. The weight of evidence from the above-described analysis suggests that there is a tangible risk reduction achieved by preventing exposure to the plume.

3.2 J-2 NORTH CONCEPTUAL SITE MODEL

The following sections present the conceptual site model for the J-2 North plume. Relatively recent modeling and investigative results have been used to aid in developing the site conceptual model.

In Disposal Area 2, the presumed source area, RDX, HMX and perchlorate reside on the soil surface as particulates and residuals deposited as a result of historical activities. The contaminants may be concentrated (e.g., in burn pits in Disposal Area 2) or more diffuse, in the form of particulates. Water from rain and snowmelt passing through the soil dissolves these soluble contaminants and they become mobile and leach through the vadose zone to the water table, which is approximately 110 feet below the ground surface in the suspected J-2 North plume source area. Currently at the J-2 Range, contaminants are present in both soil and groundwater, indicating that source contamination has not been completely dissolved and may represent a residual source. The existence of a continuing source is substantiated by the presence of low concentrations of RDX and perchlorate near the water table beneath the J-2 Range (Figure 2-1a, Figure 2-1b). It is noted that concentrations in the source area are significantly lower (more than an order of magnitude) in source area wells as compared to areas downgradient, indicating a declining source term. Furthermore, as discussed in Section 2.2.3.2, recent J-2 Range soil RRA activities have removed a significant volume of contaminated soils that had contributed to groundwater contamination.

The J-2 North plume migrates through an unconfined aquifer that is primarily composed of sandy glacial outwash, which is highly transmissive. Recharge occurs through precipitation and water loss is primarily due to evapotranspiration. The sandy nature of the surface soils promotes maximum infiltration with little run-off to surface water bodies. Silty deposits occur in the mid and lower sections of the aquifer near the J-2 Range. As expected, these silty units exhibit lower K and lower average groundwater flow velocities than are evident in the more permeable sands. Several of these silty glaciolacustrine deposits coincide with the lower extent of the J-2 North plume. The base of the unconsolidated aquifer is bounded by granodiorite bedrock. In some places, glacial till (composed of poorly sorted sediments) overlies bedrock.

The current conceptualized downgradient extent of the main body of perchlorate contamination is approximately 7,800 ft. north-northeast from the source area (Figure 1-4). The plume, from the source area, widens to approximately 2,300 ft. at its widest point, near Wood Road (approximately 2,900 ft. downgradient of the source area), and then tapers to approximately 300 ft. at the projected toe of the plume. The core of the main body of the J-2 North perchlorate plume plunges from approximately 68 ft. msl at the source area to approximately –35 ft. msl 2,600 ft. downgradient, where the downward trajectory levels off and stays nearly flat for approximately 3,500 ft., where it begins to drop in elevation to approximately –40 ft. msl at the toe of the plume (Figure 2-1b). The plume is projected to be approximately 50 ft. thick where the trajectory flattens out (near Wood Road), and approximately 10 ft. thick at the toe of the plume. In addition to the main perchlorate plume, there is a deeper, non-contiguous, area of perchlorate contamination detected at monitoring well MW-289M1 which is projected to have migrated as far downgradient as MW-293M1 (perchlorate was detected in drilling profile samples collected during drilling of MW-293 but has not been detected in the wells installed at this location). This area of perchlorate is projected to be approximately 2,800 ft. long and approximately 35 ft. thick. Its depth in the aquifer indicates that the source area is most likely upgradient of the J-2 Range Disposal Area 2. Because of its depth and observed silts and silty sands at similar depths, the perchlorate in this area is likely to become bound in low K zones and is unlikely to migrate as far downgradient as the more shallow J-2 North perchlorate plume.

The RDX plume, as currently conceptualized, extends approximately 4,200 ft. north-northeast downgradient from the source area, and is approximately 700 ft. wide at its widest point, along Wood Road (Figure 1-3). As with the perchlorate plume, there is also RDX detected deeper in the aquifer at monitoring well MW-289M1, suggesting a source further upgradient than J-2 Range Disposal Area 2 (Figure 2-1a). The concentration of RDX has remained relatively consistent over three sampling events, and has not been detected down gradient at monitoring well MW-300M1 or MW-293M1, suggesting that either the RDX is being bound in the silt/clay (low K) units as it migrates downgradient, or that the source for this contamination is more recent than the perchlorate source.

Additionally, there is another lobe of non-contiguous RDX contamination located approximately 800 ft. east-southeast of the main J-2 North RDX plume, centered around monitoring well MW-322 (Figure 1-3). This lobe of RDX is estimated to be approximately 600 ft. long and 270 ft. wide, flowing in the same general direction as the main J-2 North RDX plume. The geometry of this lobe is estimated based on the length-to-width-to-thickness ratios of the main body of the J-2 North RDX plume. The main J-2 North RDX plume plunges in a similar fashion to the perchlorate, described above, and begins to flatten out at approximately the same distance downgradient from the source area as the perchlorate; however, because the RDX plume has not migrated as far downgradient, the RDX does not begin to drop in elevation as does the perchlorate plume. The lobe of RDX centered around MW-322M1 is approximately 40 ft. deeper in the aquifer indicating a more upgradient source.

Although the J-2 North plume contains HMX, the plume extent is largely defined by the distribution of RDX and perchlorate contamination. Also, groundwater concentrations of HMX in the J-2 North plume are much lower than the health advisory level (400 µg/L). Thus, the J-2 North plume conceptual model focuses on the nature and extent of RDX and perchlorate contamination. The maximum concentrations of RDX, HMX and perchlorate in monitoring wells located in the J-2 North plume are 11 µg/L, 3.8 µg/L and 140 µg/L, respectively. Section 5.0 provides more details of the plume's vertical distribution and internal concentration gradients.

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4.0 REGULATORY CONSIDERATIONS

This section discusses regulatory considerations pertinent to the design and implementation of an RRA for the J-2 North plume (Table 4-1). The action proposed consists of pre-fabricated, containerized ETI systems to capture and treat perchlorate- and explosives-contaminated groundwater associated with the J-2 North plume.

4.1 DRINKING WATER STANDARDS

The Massachusetts groundwater discharge regulations under 314 CMR 5.00 et. seq. govern the discharge of treated groundwater and require, in 314 CMR 5.10(3), that the concentrations of discharge effluent be adequate to assure the attainment and maintenance of the assigned groundwater quality standards of the receiving waters, as listed in 314 CMR 6.00 et seq. The minimum standards for Class I groundwater (MADEP has classified MMR groundwater as Class I), as listed in 314 CMR 6.06(1), are equivalent to the SDWA Maximum Contaminant Levels (MCLs). The treated effluent will meet these levels prior to discharge to the ground. Details of the system performance sampling will be provided in a System Performance Monitoring plan.

The EPA has promulgated SDWA MCLs (40 CFR 141-143) that are enforceable standards for public drinking water supplies. The standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health. Cleanup goals established for the J-2 North action considered federal MCLs and Massachusetts MCLs (MMCLs) (310 CMR 22.00 et. seq.). The J-2 North plume contaminants (perchlorate and RDX), do not have established federal MCLs or MMCLs. Therefore, other criteria (Lifetime Health Advisories [HAs] and Drinking Water Equivalent Levels [DWELs]) were considered.

HAs establish the concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic effect over a lifetime of exposure with a margin of safety. A DWEL represents the concentration of a substance in drinking water that is not expected to cause any adverse non-carcinogenic health effects in humans over a lifetime of exposure. The DWEL is calculated assuming that all exposure to the chemical comes from drinking water. For RDX, EPA recommends a HA of 2 µg/L.

Although there is no drinking water standard for perchlorate, EPA has issued guidance regarding perchlorate cleanup levels. The EPA issued interim guidance in 1999 that recommended using provisional cleanup levels in the range of 4 to 18 µg/L for perchlorate in drinking water (EPA 1999). In January 2003, the EPA issued guidance that reaffirmed its 1999 interim guidance, with an added suggestion to carefully consider the lower end of the provisional range (EPA 2003). The Agency considered this range to be fully protective taking into account the most sensitive receptors and noted that no additional adjustment for childhood exposure was needed (EPA 2003). In February 2005, following completion of a National Academy of Sciences' report analyzing the potential health impacts of perchlorate, EPA established an official reference dose (RfD) of 0.007 mg/kg/day. EPA's RfD, which assumes total intake from both water and food sources, is appropriate and protective of all populations, including the most sensitive subgroups. EPA's new RfD translates to a DWEL of 24.5 ppb.

4.2 ADDITIONAL REGULATORY CONSIDERATIONS

The Federal Hazardous Waste Operations and Emergency Response regulations (29 CFR 1910.120) describe training, monitoring, planning, and other activities required to protect the health of workers performing hazardous waste operations. These regulations will be followed to protect the health of the workers during remediation activities that may involve hazardous waste. Federal Occupational Safety and Health Administration regulations for construction (29 CFR 1926, Subpart P) are also available and define safety requirements for construction and excavation activities. Work crews will fulfill these requirements, as applicable.

4.3 MADEP REVIEW

MADEP has a review process for a response action based on the type of release, site conditions, and receptors. Each of these items is discussed in this draft RRA plan along with additional information pertaining to response action objectives, specific plans for the action, schedules, and approach for environmental monitoring.

A description of the release and site conditions is provided in Sections 2.1, and 3.0. Response actions undertaken to date at the site are addressed in Section 2.2. The reasons for implementing a response action and any associated requirements are addressed in Sections 1.0 and 3.1. The objective(s), specific plan(s), and the implementation schedule considerations for the response action, including sketches of the remedial alternatives installations are addressed in Sections 1.0, 5.0, and 7.0. Discussions regarding whether remediation waste will be excavated, collected, stored, treated, or reused at the site are presented in Sections 4.2 and 5.0. The proposed environmental monitoring plan for implementation during and/or after the response action is addressed in Section 6.0.

4.4 REMEDIAL ACTION OBJECTIVES

Remedial Action Objectives (RAO) are established to define the goals for remedial actions. RAOs are generally established after the conclusion of a site investigation if sufficient data is available to clearly define what action is necessary to support public health, or after the conclusion of the baseline risk assessment. The following sections describe the RAOs for this interim action (RRA) as described in this plan and how the RAOs for the final remedy will be established.

4.4.1 Rapid Response Action

The RAOs for the RRA include the following:

- plume migration management, and
- contaminant mass removal.

Control of migration of the plume is an important consideration for the J-2 North plume as public water supply well WS-2 is situated downgradient of the perchlorate contamination. Fate and transport modeling suggests WS-2 is situated approximately 16 years downgradient of the leading edge of the perchlorate plume (as defined by 1 µg/L). Contaminant mass removal is also a goal for the RRA as focused mass removal will serve to accelerate plume remediation and shorten the timeframe for aquifer restoration.

4.4.2 Comprehensive Remedy

Specific RAOs for the J-2 plume will be developed following completion of the groundwater characterization report (Remedial Investigation equivalent), baseline risk assessment, and planning stage for the feasibility study. It is likely that the RAOs for the comprehensive remedy will be consistent with the RAOs established for the RRA; however, they may differ depending on the findings of the risk assessment and establishment of promulgated standards for perchlorate and explosives. The J-2 Range North Groundwater Rapid Response Action; however, will support any future RAOs through removal of contamination and migration management.

5.0 CONCEPTUAL DESIGN OF THE ETI SYSTEM

This section presents the methodology used to develop the conceptual design for the J-2 North plume ETI System based on the site conceptual model, groundwater modeling, relevant regulations, treatment technology evaluations, bench-scale studies, and other engineering considerations. With input from the EPA and MADEP, extraction, treatment, and infiltration was selected as the remediation approach because of its effectiveness and compatibilities with likely future comprehensive response actions.

5.1 EXTRACTION SYSTEM

This section describes the development and use of the J-2 groundwater flow and transport model to evaluate several remedial system designs and conduct sensitivity testing of plume shell configuration, system flow rates and screen length/position. The following sections present the model development and calibration, the wellfield scenario simulations and the proposed wellfield design.

5.1.1 J-2 Model Development

Groundwater modeling was used as the primary tool for evaluating the feasibility of preventing further migration of the J-2 Range plume and remediating the plume by affecting mass removal. Potential wellfield scenarios were evaluated with a zoom model combined with either solute transport analyses or particle tracking analyses. The zoom model developed for this work (the J-2 model) differs from the model used for the J-3 RRA modeling. The domain of the J-2 model was extended north to the Cape Cod Canal and Cape Cod Bay and the grid discretization was refined for transport in the J-2 study area.

Due to the need for solute transport analysis, the numerical model *MODFLOW-SURFACT* (HydroGeoLogic 1999) was selected for this work. *MODFLOW-SURFACT* was used for the flow and transport model because it is a robust, widely applied model that has been extensively verified. Particle tracking results were obtained with *SplitPath* (HydroGeoLogic 1998a), which is a proprietary particle tracking code written for use with *MODFLOW-SURFACT*. *SplitPath* was verified during modeling of the Air Force Center for Environmental Excellence / Installation Restoration Program's (AFCEE/IRP) Sandwich Road treatment plant's remedial design by comparing *SplitPath* solutions to two-dimensional and three-dimensional (3D) analytical solutions for flow to extraction wells (AFCEE 2000, HydroGeoLogic 1998a). *SplitPath* results were nearly identical to the analytical solutions under all the conditions tested. The model was built in *BUILD3D* (P^2T 1998), and flow simulations and calibration were performed using the *MODFLOW-SURFACT* software package.

Creation of plume shells (3D contaminant concentration distributions) was completed using geostatistical assignment of spatially distributed data through the kriging process. Kriging was performed using the *KT3D* module of GSLIB (Deutsch and Journel 1998), which was extended (program code revised) to estimate concentrations around single points in a manner consistent with kriging, which requires two or more points. Results were visualized using the Department of Defense's Groundwater Modeling System, version 2.1 (*GMS*) (EMS-i 1999). Additional codes developed for seeding of plume shells in the numerical model are discussed in Section 5.1.3.

Post-processing of model output was performed with a variety of programs including *Tecplot*™ (Amtec Engineering Inc. 2001), *AutoCAD*® (AutoDesk 1998), and *Groundwater Vistas*™ (HydroGeoLogic 1998b). A variety of customized applications using *Microsoft Excel*® and specialty *Microsoft Visual FORTRAN*® and *Microsoft Visual Basic* language programs were developed to aid in the post-processing of model results. These programs were used to quantitatively evaluate the solute transport models. These computations include time series analysis of mass removal; extraction and water supply well influent concentrations; maximum concentrations; plume volumes; estimated clean-up times; and to determine the relative percentage of mass removed by pumping, adsorption and model outflow. These tools have been utilized at several MMR sites currently undergoing active remediation. These include FS-12, LF-1, CS-10, SD-5 South and Ashumet Valley.

The 2001 AFCEE regional model (AFCEE 2002) was used as the basis for model refinement and the development of the J-2 model. The regional model is the repository for all site characterization data and is periodically updated with new lithologic and pumping stress information.

5.1.1.1 Model Domain and Boundary Conditions

The J-2 Model domain and grid is shown on Figure 5-1. Constant head boundaries are used on all sides of the model based on the regional model solution. Recharge coverages are the same as in the 2001 AFCEE regional model and average 31.5 inches/year.

5.1.1.2 Discretization

Discretization of the J-2 Model domain is shown on Figure 5-1. Discretization is variable with a maximum 500-foot spacing near the boundaries and a minimum 50-foot spacing in the study area. Layer thickness ranges from 1.1 feet near the water table to 19.3 feet near bedrock. The model has 40 layers with 3,746,240 active cells.

5.1.1.3 Hydraulic Conductivity and Porosity

The J-2 Model is based on the 2001 AFCEE regional model gradational K field. Within the model domain, MPP K values range from 70 to 280 feet/day with anisotropy ratios ranging from 3:1 to 25:1. The BBM and SM K values range from 22 to 150 feet/day and 39 to 106 feet/day, respectively. Lake and pond K values are 1,000,000 feet/day. The porosity (0.3) is consistent with previous regional and subregional models.

The 30 percent aquifer porosity used for the plumes is consistent with previous AFCEE modeling at MMR and has been determined to accurately simulate plume migration rates on western Cape Cod. A range of effective porosity values have been reported for sediments beneath the MMR. The porosity value used for Demo 1 and Central Impact Area was 0.35. The porosity value used for CS-19 and FS-12 was 0.30. Porosity values for all plumes at MMR range from 0.30 to 0.39. Evaluation of more than 200 grain-size analyses from borings across MMR suggests that aquifer porosity averages 0.30. For the conceptual hydrogeologic model, a single porosity value of 0.30 was adopted for the modeling effort.

Several low-K silt and silty-sand units, evident from borehole logs, were incorporated into the J-2 Model. The addition of these units resulted in a better match between modeled and observed plume travel times and trajectories. These low-K units impede erroneously deep plume trajectories and provide results consistent with observed groundwater borehole screening sampling data.

5.1.1.4 J-2 Model Calibration Targets

The calibration of a groundwater flow model is the process of adjusting model input parameters (K and anisotropy) and boundary conditions (e.g., recharge, stream and drain conductance) to obtain a reasonable match between observed and simulated hydraulic conditions. In practice, this usually involves an iterative process of adjusting hydraulic properties and/or boundary conditions assigned in the model. Several calibration targets were used to insure reasonable calibration of the J-2 flow and transport model.

<u>Water Table Configuration</u>

Spatial distribution of monitoring wells and availability of groundwater elevation data were important considerations in selecting the most appropriate water level data points to use for the J-2 Model calibration. Another consideration was the density of data from the various events and whether the data were representative of average conditions. Typically, average water level measurements made over an appropriate period, or a synoptic event representative of long-term average conditions, are used during model calibration to represent steady-state conditions.

As a first step in model calibration, the 2000 synoptic groundwater elevations were mapped along with model-predicted values (Figure 5-2). A comparison of the shape of the contours indicates that the modeled contours are in general agreement. Overall, the head match is good, indicating that the combination of model inputs is reflective of observed water table conditions. This match in water table slope suggests that the model should be a good predictor of groundwater flow directions.

<u>Head Residuals</u>

Head residuals, also known as water level residuals, are defined as the difference between observed and model simulated groundwater elevations. Positive residuals indicate that the model is under-predicting the hydraulic head; whereas, negative residuals indicate that the model is over-predicting the head. For the J-2 Model, the water level calibration target data sets include groundwater elevation data from May 2000 – February 2001. This composite data set contains over 1,100 water level measurements (388 within the J-2 model domain) and is considered to represent average water level conditions for western Cape Cod. Although data from the 2000 synoptic event were used for model calibration, data collected during the 2003 and 2004 synoptic events were also utilized to refine the conceptual model of plume trajectory and migration. These evaluations were conducted during model calibration and compared to the known trajectory of the J-2 plume.

Normally, a calibration is considered good if the ratio of the residual standard deviation to the head range is less than 10 to 15 percent (ASTM 2002). The ratio of residual standard deviation (0.99 feet) to the head change across the model (33.31 feet) is 3.0 percent, indicating a very good calibration. The ratio of residual standard deviation to the head change in the parent 2001 regional model is 1.7 percent. This indicates excellent calibration of the regional and J-2 models and indicates the J-2 Model should be a good predictor of groundwater flow conditions.

<u>Plume Trajectory and Length</u>

Particle tracking and solute transport simulations were also used to calibrate the SE range model. The particle tracking analysis examined the vertical and horizontal plume trajectories, as well as the timing of plume development.

Particle tracking is a simple form of contaminant transport analysis. It does not include the effects of dispersion, retardation, or chemical reactions. *SplitPath* was used to perform particle tracking. The particle tracking analysis serves as a check on model calibration by allowing comparison of simulated and observed migration pathways. Particle tracking also can be used to make decisions regarding the adjustment of model layer K to ensure that the model-simulated groundwater velocities are consistent with the estimated plume velocities derived from source histories and plume size.

The J-2 flow model was calibrated qualitatively to the perchlorate plume trajectory. In a 35-year period of simulation, forward tracking particles from the source area approximate the longitudinal extent of the plume (Figure 5-3). As noted, the particle tracking does not include the effects of longitudinal dispersion, which would reduce the predicted travel time. Previous calibrations of the SE Ranges and J-2 Models indicated the vertical trajectory and longitudinal velocity of the J-2 plume were significantly improved by refining the vertical discretization of the upper portion of the model.

Helium and Tritium Age Dating Comparisons

Groundwater age data from the U. S. Geological Survey (USGS) were compared with the age of reverse particle tracks calculated from the sampling locations (well screens) back to the origin of the water at the water table surface. The USGS estimated the age of groundwater from analyses of tritium and helium. The reverse particle tracks originated from the well screens in the model that were sampled by the USGS. A comparison of model-predicted and observed travel times indicates that most of the predicted travel times are not as long as the age dating suggests (Table 5-1). This implies model particle velocities may be greater than velocities interpolated from the age dating. There appears to be no bias in the comparison related to depth. It is noted that groundwater velocities calculated from field head data agree very closely with the modeled velocities.

5.1.2 J-2 Transport Model Development

The J-2 transport model is based on the calibrated 2004 J-2 flow model. To model solute transport, input parameters were developed to describe hydrodynamic dispersion, retardation, and degradation processes. These parameters include dispersivity, soil/water partition coefficient (K_d), and contaminant half-life. Contaminant release mechanisms or processes (such as source location and release history) and present contaminant distribution are also important. Bulk density and porosity are physical parameters of the aquifer matrix that also influence contaminant transport. The RDX and perchlorate concentration plume shells served as initial conditions for the solute transport model.

This section discusses those physical, chemical, and biological processes that potentially influence contaminant fate and transport of RDX and perchlorate in the J-2 plume area. These include:

- advection;
- hydrodynamic dispersion;
- retardation;
- biodegradation; and
- reactive transformation.

5.1.2.1 Parameters Controlling Advection

Advection involves physical transport of contaminants entrained in flowing groundwater. Advective flow paths delineated by particle tracking provide a first-order estimate of where and when contaminants are likely to migrate. Advection is important in the J-2 solute transport modeling because advection is the primary transport mechanism for this plume. Model parameters that control advection include hydraulic gradients, vertical and horizontal K, and porosity. These parameters have been previously discussed in the *Final Plume Response Groundwater Modeling Report* (AFCEE 1999a), the *Final J-3 Range Groundwater Rapid Response Action (RRA) Plan* (ECC 2005), and *Draft 2002 SPEIM Groundwater Models and Regional Groundwater Flow Model Transition Report* (AFCEE 2003a). Values for these parameters were estimated from head measurements taken in the J-2 area, the conceptual model of the aquifer, information developed during the course of previous modeling efforts performed at MMR, and through model calibration.

5.1.2.2 Hydrodynamic Dispersion

Hydrodynamic dispersion refers to the spreading of a solute by the combined action of mechanical dispersion and molecular diffusion. Dispersion causes some of the solute to move faster and some to move slower than the average linear velocity of groundwater. Mechanical dispersion is caused by the variations in the magnitude and direction of velocity of groundwater. Molecular diffusion results from solute concentration gradients, which cause the solute to move from regions of higher concentration to regions of lower concentration. On western Cape Cod, molecular diffusion is insignificant relative to mechanical dispersion, and thus is omitted in solute-transport modeling. Solute-transport modeling uses longitudinal, transverse, and vertical dispersivities to describe the mechanical dispersion in a 3D porous medium. Dispersivity is an aquifer property and is not contaminant-specific.

Quantification of dispersion is complicated by the scale effect where apparent dispersivity increases with the length of a plume for the same geologic media and location. Apparent dispersivity is based on field observations and its value is normally attributed to the effects of heterogeneities on the macroscopic flow field. A number of modeling studies with calibrated dispersivities for plumes in glaciofluvial sediments have shown the scale effect (Spitz and Moreno 1996). Longitudinal dispersivities tabulated for these studies are about 100 times less than the travel distance (plume length). Transverse and vertical dispersivities typically range from 0.3 to 0.01 times the longitudinal dispersivity. A tracer test in Ashumet Valley reported a longitudinal dispersivity of 3.0 feet, with a transverse dispersivity of 0.06 foot and a vertical dispersivity of 0.005 foot (Garabedian et al. 1991). These dispersivities agree closely with dispersivities estimated from statistical properties using flowmeter K data (Hess et al. 1991). Other reported dispersivities include longitudinal (3 feet), transverse (0.05 foot) and vertical (0.005 foot) components (AFCEE 1999a) that provided a reasonable simulation of particle tracks compared to observed contaminant distributions. A modeling approach was also used to estimate dispersivities based on the use of boron as a conservative tracer in the Ashumet Valley plume (AFCEE 1999b). A longitudinal dispersivity of 3.5 feet, a transverse dispersivity of 0.35 feet, and a vertical dispersivity of 0.035 foot were used to achieve calibration for the Ashumet Valley site.

Longitudinal, transverse and vertical dispersivities used in the J-2 Model are 10, 0.3 and 0.03 feet, respectively. These dispersivities were calibrated by matching the predicted and observed plume characteristics from contaminants emanating from the J-2 Range Disposal Area.

5.1.2.3 Retardation

Adsorption of contaminants to the aquifer matrix retards their rates of migration. The retardation factor (R_f) is defined as:

$$R_f = 1 + K_d \frac{\rho_b}{n_e} \tag{1}$$

Where: ρ_b = bulk density of the soil (g/cm^3),
n_e = effective porosity of aquifer matrix (ratio), and
K_d = soil/water partition coefficient (g/mL).

For a given mass of contaminant, the fraction available for advective transport is influenced by the adsorptive properties of the soil matrix. The soil/water partition coefficient (K_d) describes the ratio of adsorbed to dissolved contaminant:

$$K_d = \frac{C_s}{C_{aq}} \tag{2}$$

Where: C_s = concentration of solute in soil (mg/g), and
C_{aq} = concentration of solute in aqueous solution (g/mL).

For this modeling effort, it was assumed that total porosity is equivalent to effective porosity. Total porosity is the total void space in the medium whether or not it contributes to fluid flow divided by the total volume of the medium. Effective porosity is the total volume of the void spaces in the medium through which water can travel divided by the total volume of the medium. A total porosity of 0.30 and a bulk density of 1.68 g/cm^3 were used, consistent with previous AFCEE modeling at MMR.

A K_d value of 0 mL/g was used to model retardation of perchlorate and a value of 0.009 mL/g was used to model retardation of RDX in the J-2 plume area. The K_d value was calculated from the product of an average percent organic carbon fraction (F_{oc}) of 0.038 for the MMR aquifer and an organic-carbon/water partition coefficient (K_{oc}) of 23.5 mL/g. Using these parameters, a retardation factor of 1.0 was calculated for perchlorate and 1.05 for RDX. These parameters are identical to those used for the recent J-3 RRA transport modeling.

5.1.2.4 Degradation and Reactive Transformation

Degradation in groundwater refers to chemical changes in a contaminant due to microbial activity either in the presence of oxygen (aerobic) or in its absence (anaerobic). These changes transform a contaminant into another distinct chemical constituent. Degradation rates are stated in terms of the half-life of a contaminant. The half-life of a constituent ($t_{½}$) is the time for one half of the total mass to decay. The decay rate (λ) is specified as:

$$\lambda = \ln(2) / t_{½} \qquad (3)$$

The half-life of a contaminant varies greatly in various environments. The half-life data found in the relevant literature for perchlorate and RDX are not well constrained. For this reason, no decay has been used during solute transport simulation for RDX and perchlorate in the J-2 plume. This assumption will produce a conservative estimation of likely restoration time frames and required flow rates necessary to capture the plume.

Reactive transformation data for perchlorate and RDX are also not well constrained. For this reason, no transformation has been used during solute transport simulation.

5.1.3 Plume Shell Development

In order to perform contaminant transport simulations, the J-2 Model was initialized with current-condition groundwater contaminant concentrations. This was accomplished through development of the J-2 North 2004 contaminant shells, both for RDX and perchlorate, and re-gridding of the shell grid data to the model grid. Plume shells were prepared to incorporate new data and to address data gaps.

Data sets of groundwater sampling results representative of current contaminant concentrations were compiled. These results were geostatistically interpolated (kriged) to a 3-D model grid to provide the model with the initial concentration conditions. The kriging software cannot map to 3-D grids with variable layer thicknesses (as is the case for the J-2 model), so the contaminant concentrations were kriged to a regular grid (i.e., the kriging grid), and these concentrations were re-gridded to the J-2 model grid. The following sections describe the development of the J-2 North 2004 contaminant shells.

5.1.3.1 Data Compilation and Migration

Data were queried from the Environmental Data Management System, the centralized database for the IAGWSP, via the Site Environmental Evaluation (SEE) database. The plan view geographic range of these sample data were selected to ensure all in-plume samples were accounted for, as well as samples within a sufficient distance outside the conceptual edge of each plume to define the lateral plume extent.

Samples representing "current" conditions have dates ranging from October 2003 to September 2004. These data were supplemented with older data from September 2000 through September 2003, which were migrated in the groundwater flow regime of the J-2 Model using *Splitpath* (HydroGeoLogic 1999) and using a year-based (October through September) grouping. These migrated older data provided estimates of current conditions in areas downgradient of monitoring wells, and filled spatial gaps in the data coverage. The maximum migration was three years. The data were migrated without degradation, retardation, or dispersion.

The final kriging data sets included groundwater samples collected from wells and boreholes (borehole screening samples collected during drilling). A concentration value of zero was substituted for all contaminant nondetect results.

5.1.3.2 Assignment of Contaminant Concentrations to a 3-D Grid

The following discussion is only a brief summary of the kriging method and its extension for single (isolated) points, and presumes a working knowledge of the terms and concepts relating to geostatistical assignment of spatially-distributed data through the kriging process. Additional information on kriging can be found in Deutsch and Journel (1998) and Isaaks and Srivastava (1989).

<u>Software</u>

Kriging was performed using an extended version of the *KT3D* module of GSLIB (Deutsch and Journel 1998), revised to estimate concentrations around single points in a manner consistent with kriging, which requires two or more points. Results were visualized using

GMS (EMS-i 1999). GMS Version 2.1 has been utilized for analysis of several MMR sites currently undergoing active remediation. These sites include FS-12, LF-1, FS-1, CS-10, SD-5 South, and Ashumet Valley.

The extended *KT3D* module was initially developed and applied to optimization of the SD-5 and CS-10 monitoring well networks (AFCEE 2003b). In the case in which there is only one nearby sample, the estimated concentration should decrease smoothly toward zero with increasing distance from the sample.

Making use of the assumption that the concentration is zero in the absence of a nearby sample, solitary samples are no longer ignored, but instead affect concentrations within an ellipsoid surrounding the sample. Dimensions of this ellipsoid are determined by the kriging range and anisotropy parameters. This behavior is in accord with conceptual expectations for a solitary sample: at small separation distances, the sample can tell a great deal about the likely contaminant concentration, but at larger separation distances the credibility of the sample declines, finally reaching the point of providing no information at separation distances beyond the kriging range.

Kriging the Plume Shell

The domain of the cell-centered J-2 North 2004 kriging grid was defined by the parameters presented in Table 5-2. Parameters governing kriging are summarized in Table 5-3. The contaminant concentration data sets were mapped to the kriging grid using the extended *KT3D* program described in the previous section.

For each contaminant shell, the 3-D cell-centered uniform grid (i.e., all cells have the same dimensions) with no rotation (i.e., X, Y, and Z dimensions correspond to easting, northing, and elevation dimensions, respectively) was used. The grid was defined orthogonal to site coordinates and the groundwater transport model grid. A set of input parameters for *KT3D* was created for each kriging zone.

Kriging permits sensitivity to nearby observations to vary with direction as well as distance. This anisotropy is adjusted so that the direction of maximum sensitivity coincides with the direction of groundwater flow. Transverse and vertical search radii coincide with the directions of the lateral and vertical dispersivities used in transport equations, and are similar in proportion, reflecting their close relationship. The magnitude of the dispersion, and hence the anisotropy, is assumed to be constant over the length the plume. A value was selected for the longitudinal range that provides a reasonable compromise between preserving detail in areas with high sample density and minimizing the number of control points needed to fill gaps between more widely separated observations.

Groundwater flow directions in plan view are nearly uniform over the area of the J-2 plumes. Groundwater flow directions vary in the vertical direction along the length of the plume, with a downward component at the trailing edge, becoming essentially horizontal roughly midway through the longitudinal extent of the plume and beyond. The downward component occurs because of proximity to the top of the regional groundwater mound, where accretion of recharge is the dominant process. Plan-view outlines were manually constructed for each of the contaminants of concern (RDX, perchlorate) for four zones, as illustrated in Figure 5-4, with kriging orientations as listed in Table 5-3. The Deep kriging zone underlies both the Upgradient and South zones and is larger in lateral extent with respect to RDX Upgradient and South zones. Masking arrays were created for each of the outlines, separately for each zone, and were used to isolate kriging results to the appropriate zones.

A small proprietary program, *AddMask* (Jacobs 2002), was used to step through the kriging and mask data sets simultaneously, retaining the kriged concentration value for each zone. The four zone arrays were added together using the proprietary program *AddShell* (Jacobs 2003a) to produce a complete concentration field (shell) for each J-2 plume.

The final component of kriging was the placement of control points (artificial location-concentration data) to fill gaps between widely separated observations. Control-point concentrations were selected to produce smooth changes in concentrations between observations consistent with the conceptual model, which was based on hydrology, other nearby observations, and estimated source history.

The contaminant concentrations were contoured and visualized using wire-net iso-surfaces drawn by *GMS*. The final base case J-2 North 2004 plume shells are shown in plan view in

Figure 5-5 (base case shells). Sensitivity plume shells were developed as a means to evaluate uncertainty and wellfield design robustness and are presented in Figure 5-6.

The kriging parameters and control points were adjusted until the resulting contaminant shell fit the known data as closely as possible and was hydrologically plausible. The estimated detection limit for RDX (0.25 µg/L) and the MADEP interim guidance level for perchlorate (1.00 µg/L) were considered to be the outermost boundary for development of each base case contaminant shell. The detection limit was used for development of the RDX plume shell due to the relatively small lateral extent of the RDX plume above the EPA HA level (2.00 µg/L). The resulting base case RDX plume shells, however, are depicted with concentrations above 2.00 µg/L.

Mask boundaries were developed to fit the kriged concentration fields to the conceptual model of the respective plan-view boundary for each contaminant. These masks function as plan-view 'cookie-cutter' restrictions on kriging (in the x-y dimensions only; kriging results were not masked in the vertical dimension), as well as guides for filling in the plan view extent of each shell to mimic the conceptual model. The base case plume shells used for wellfield testing are presented in Figure 5-5 showing the RDX plume shell down to the EPA-recommended HA level of 2.00 µg/L and the perchlorate plume shell down to the MADEP interim guidance level for perchlorate of 1.00 µg/L. Model input includes all concentrations without a concentration cut-off (see Table 5-4 for total mass, mass above cut-off, and mass in model grid). The base case RDX plume shell shown to the estimated detection limit (cut-off) is presented in the data density analysis (Figure 5-7; discussed in Section 5.1.3.5).

To support sensitivity testing of the 2004 plume shells, modeling, and resultant wellfield design, an expanded-volume perchlorate plume shell and an expanded-mass plume shell were created as revisions of the base case perchlorate 2004 plume shell. These sensitivity plume shells are presented in Figure 5-6.

The total water (aqueous) volume and dissolved mass of each shell was calculated using the proprietary program *PlumStat* (Jacobs 2003b). This program calculates total and above cut-off mass and utilizes aquifer porosity to calculate the total and above cut-off volume of contaminated groundwater. Plume shell statistics are listed in Table 5-4. A porosity of 30 percent was assumed for the J-2 area. The volume of contaminated groundwater in the base case J-2 North RDX 2004 plume shell with RDX concentrations greater than or equal to a cut-off (estimated detection limit) of 0.25 µg/L was 17.3×10^6 $ft.^3$. The RDX mass associated with concentrations greater than 0.25 µg/L was 0.75 kilograms (kg). The volume of contaminated groundwater in the base case J-2 North perchlorate 2004 plume shell with perchlorate concentrations greater than or equal to a cut-off (estimated detection limit) of 0.35 µg/L was 90.7×10^6 $ft.^3$. The perchlorate mass associated with concentrations greater than 0.35 µg/L was 29.4 kg.

5.1.3.3 Sources of Uncertainty

There are several sources of uncertainty that contribute to the overall uncertainty in the contaminant shells, including the initial data sets, the migrated data sets, the kriging process, masking of the plume boundaries, and the assumed porosity. Some additional uncertainty may be added by re-gridding the shells for use with the transport model, which is the primary use of the plume shells. Low levels of uncertainty may be added in the re-gridding process, which typically smoothes and lowers the kriged contaminant concentrations (by small amounts and only in isolated areas) and clips (removes) any portion of the shell that lies outside of the model grid.

The largest source of uncertainty is associated with the limited horizontal and vertical density of observations. As with nearly all environmental data sets, the relatively coarse characterization of field contaminant concentrations increases the possibility that the highest contaminant concentration in the plume was not measured. Variable data density, such as in the vicinity of a borehole with borehole screening data collected every 10 feet vertically, may also skew the kriging averaging process. Older groundwater sampling data were migrated without retardation, degradation, or dispersion to their probable present locations in areas of the plume between widely-spaced sampling locations. It should be assumed that the concentration at the migrated data point was less than that used for kriging, and the location is an estimate dependent upon the model flow regime. With recent data as used for these plume shells, it is unlikely that dispersion has had a significant effect on these concentrations.

Masking of the contaminant shell in areas with sparse data coverage can introduce uncertainty to the shell boundaries. This also has an effect on the calculated plume volumes and, to a lesser degree (due to low concentrations at the periphery of the shell), the calculated plume mass. The assumed aquifer porosity has a linear relationship to the calculated plume volumes and contaminant masses. The aquifer porosity used for the plumes was 30 percent, as is used for numeric groundwater modeling of the J-2 area. Calculated (kriged) concentrations are independent of porosity, and the shell mass is considered to exist in the available pore spaces represented by an effective porosity of 30 percent. Thus, the concentrations are assumed to be zero in the matrix. Assuming 20 percent porosity would reduce calculated plume water volumes by one-third, while using 40 percent porosity would increase the calculated plume water volume by one-third.

5.1.3.4 Sensitivity Plume Shell

Two sensitivity plume shells were prepared to evaluate some of the potential uncertainties in representation of the plume through the use of plume shells and to evaluate the wellfield design robustness. Perchlorate was selected based on the larger lateral extent relative to the conceptual model of the RDX plume.

An expanded-mass plume shell was created from the base case perchlorate 2004 plume shell increased perchlorate concentrations (revision and addition of control points) to produce a higher maximum concentration (450 µg/L vs. 370 µg/L in the base case shell) and an area of higher mass than conceptualized with the available data. An expanded-volume plume shell utilized revision of the base case shell, with minor lateral expansion of the mask boundaries (expanded-volume masks), revision of peripheral control points (revision of selected peripheral control points and addition of peripheral control points), and kriging the revised concentration data set with the expanded-volume masks. The approximate detection limit (0.35 µg/L) was the outermost boundary for the expanded-volume perchlorate plume shell. These sensitivity plume shells are presented in Figure 5-6. Model simulations of these sensitivity plume shells and assessment of simulation results are discussed in Section 5.1.4.4.

5.1.3.5 Data Density and Assessment

Typically, a contaminant shell contains areas where measured data are sparse, and concentrations derived from interpolated and extrapolated (both measured and migrated) data need to be supplemented with additional data based on the conceptual understanding of the plume. This was the case for both the J-2 North RDX and perchlorate plumes. Therefore, control points (artificial location-concentration data) were used for both shells. Control point locations and their relative data density can be seen in both plan view and cross sectional view in Figure 5-7 and Figure 5-8. To assess the significance of control data points, these control points were excluded from kriging input data to create the Measured Data Only plume shell (right panel in each figure), which included unmigrated and migrated data. The core and edges were filled in to conform to the conceptual model of a long-lived source that would produce a continuous zone of contamination.

The J-2 North 2004 plume shells were prepared to be adequately conservative in support of wellfield testing for the response action described in this plan. Selected measured and migrated data points were removed from the kriging input data set due to data points too close in spatial position and/or in time. Many ‘migration year’ time periods for a given monitoring well included several data points. In order to restrict the overweighting that these frequent data points would produce, only one data point was used for a given monitoring well and for a ‘migration year’ time period. Additional measured data points in a migration year (beyond one selected data point per location per migration-year) were removed, typically retaining the most recent data except when a higher value from earlier in the period was retained as a mass-conservative practice.

J-2 RDX Data Assessment

Data density in the J-2 North RDX 2004 plume shell is presented in Figure 5-7 with the base case RDX plume shell mapped to a minimum concentration of 0.25 µg/L (the approximate detection limit and the spatial target for plume shell development). Without control points, the plume core consisted of one distinct hotspot (right panel in Figure 5-7). Control points accounted for about 51 percent of the RDX plume shell mass above the estimated detection limit (the RDX plume mass decreased from 0.75 kg to 0.37 kg when control points were removed from the kriging input data). The downgradient area of the plume shell was extensively filled in with control points to conform to the conceptual model of a long-lived source that would produce a continuous zone of contamination.

J-2 Perchlorate Data Assessment

Data density in the J-2 North perchlorate 2004 plume shell is presented in Figure 5-8 with the base case perchlorate plume shell mapped to a minimum concentration of 1.00 µg/L (the MADEP interim guidance level). Control points accounted for about 73 percent of the J-2 perchlorate plume shell mass above the MADEP interim guidance level (mass decreased from 29.0 kg to 7.78 kg when control points were removed from the kriging input data).

J-2 Perchlorate Sensitivity Plume Shells Data Assessment

The expanded-mass perchlorate plume shell consisted of a mass of 53.1 kg and a volume of 92.9×10^6 ft.^{3}. This was approximately 80 percent more mass and 2 percent greater volume than the base case plume shell. The expanded-volume perchlorate plume shell consisted of a mass of 29.6 kg and a volume of 94.9×10^6 ft.^{3}. This was 0.7 percent more mass and 5 percent greater volume than the base case plume shell. All mass and volume values for this sensitivity assessment were those above the estimated detection limit of 0.35 µg/L for perchlorate. The sensitivity plume shells were used in select fate and transport simulations to assess uncertainties in the base case plume shell and the robustness of the proposed wellfield design. These simulations are described and assessed in Section 5.1.4.4.

5.1.3.6 Mapping of Contaminant Shells to the Transport Model Grid

The 3-D concentrations created by *KT3D* (kriging of a 3-dimensional rectangular grid) for the J-2 North 2004 plume shells were re-gridded to the SE Ranges model grid to define the initial conditions for contaminant transport modeling. The proprietary program *MdlSeed* (Jacobs 2004) was used to perform this re-gridding. The *MdlSeed* program performs the following operations: (1) reads the concentration array of the contaminant (plume) shell created in *KT3D*; (2) for each grid cell, if the concentration is within user-specified limits, the mass is calculated using the cell volume and global porosity; (3) if necessary, clips the kriging grid to the model grid, trimming the plume to the lateral and vertical model boundaries; (4) sums the contaminant mass in each model grid cell from the portions of the kriging grid cells that are overlapped by each model grid cell; and (5) calculates a corresponding contaminant concentration for each model grid cell by dividing the total contaminant mass by the volume of the model grid cell and the global porosity.

This re-gridding process typically smoothes and lowers the kriged contaminant concentrations (by small amounts and only in isolated areas) because of differences in size and alignment between the kriging and model grid cells and the resulting averaging effect. However, the re-gridding algorithm strictly accounts for all mass; if the model grid completely encompasses the kriging grid and there are no user-specified concentration limits, the contaminant mass contained in the model grid is exactly the same (within the numerical precision of the calculation) as that contained in the kriging grid.

Table 5-4 summarizes J-2 North 2004 plume shells. These data include the percent mass retained for contaminant shells following re-gridding of each shell to the model grid.

5.1.4 Fate And Transport Modeling

Groundwater contaminant transport modeling was conducted with the 2004 J-2 Groundwater Model (J-2 model) to evaluate the model-predicted trajectory of the J-2 RDX and perchlorate and to assess potential remedial system designs to capture the J-2 plume. Potential impacts to public water supply well WS-2, specifically influent RDX and perchlorate concentrations, and potential impacts on trajectories of nearby plumes (J-1 and J-2 east) were also evaluated.

5.1.4.1 Scenario Development

Fifty-six transport simulations (Table 5-5) were conducted under both ambient conditions (with current remedial and municipal pumping at average operating conditions) and with active remediation of the J-2 plume. Simulations of active remediation of the J-2 plume featured scenarios with between one and five extraction wells (Figure 5-9) and cumulative pumping rates from 90 to 540 gallons per minute (gpm) (Table 5-5). Various well location configurations were tested, including: one-well wellfield; two, three, four and five-well extraction in an axial arrangement; cross-gradient extraction along the widest portion of the plume; various reinjection well or infiltration trench configurations; different down-gradient or in-plume well locations; differing combination of locations; differing flow rates, and varying screen lengths. In addition to evaluation of wellfield configurations, sensitivity tests were conducted to assess contaminant distribution (plume shell) uncertainty, screen length, vertical screen position and flow rate impact on performance. This testing was used to assess design requirements and to ensure that uncertainty in plume characteristics is adequately addressed in the final design scenario. Lastly, testing was conducted to assess the impact of potential continuing source contamination on plume development and design robustness. This testing focused on the appropriateness of extraction well placement and flow rate requirements to address future source area releases.

Sensitivity testing of flow rates was demonstrated by comparing capture percentages for all scenarios against their total flow rate. Two sensitivity plume shells, a mass-expansion and volume-expansion version, were developed as described in Section 5.1.3.4. These plume shells were developed to address the uncertainties related to the extent of higher concentration areas between MW-289 and Wood Road and the extent of low-level concentrations near the plume boundary. The plume shells were simulated in the model to assess the sensitivity of J-2 extraction on changes in plume shell mass and volume. Testing of perchlorate plume shell uncertainty was conducted for Scenarios 21b (mass-expansion and volume-expansion version) and 24b (mass-expansion version only). The mass expansion perchlorate plume shell included an enlarged zone of high concentrations near the core of the plume between monitoring well MW-289 and Wood Road. Sensitivity testing of screen length and screen position was conducted for perchlorate transport in Scenario 21e.

Consideration was given to the small zone of perchlorate situated deep in the aquifer near monitoring well MW-289. Based on boring logs from well MW-289 and other wells in the area, the perchlorate is situated in low conductivity silty deposits. The position of this contamination (at the base of the aquifer where average flow velocities are very low) and lack of downgradient expression of the plume (it is not present at Wood Road) suggests it is unlikely the plume is appreciably migrating. To assess the potential to extract contamination from this zone of the aquifer, testing was conducted specifically targeting this zone of contamination. Extraction of the deep mass near MW-289 was determined to be not effective because the low conductivity of the deposits prevent mass removal, and therefore, was not included as a component of the wellfield. The need for assessing the deep zone of contamination will be further evaluated during the feasibility study.

As discussed in Section 5.1.3.6, plume shells of the existing J-2 North RDX and perchlorate plumes were created and mapped into the model grid to serve as initial conditions for the transport model. The plume shells were based on a 3D interpolation of field data and represent current contaminant distribution (see Section 5.1.3.2). The total aqueous phase mass in the RDX plume shell was 0.77 kg with a maximum concentration of 11.1 µg/L. After mapping the concentrations in the transport model grid, 99.6 percent of the plume mass was incorporated into the model with a maximum concentration of 9.7 µg/L. The drop in concentration is a result of interpolation from the plume shell grid to the transport model grid by the plume-mapping program. The maximum historical and recent RDX concentrations are 11.0 µg/L (September 2003) and 5.9 µg/L (July 2004), respectively. The total mass in the model, after accounting for adsorption, was 0.80 kg.

The total aqueous phase mass in the perchlorate plume shell was 29.5 kg with a maximum concentration of 370 µg/L. After mapping the concentrations in the transport model grid, 100 percent of the plume mass was incorporated into the model with a maximum concentration of 370 µg/L. The maximum historical and recent perchlorate concentrations are 370 µg/L (August 2003) and 110 µg/L (March 2004), respectively. The total mass in the model was 29.5 kg.

Many of the simulations assumed that the start of pumping would be delayed approximately one year to accommodate additional study, design, and field implementation. The RDX and perchlorate plume shells are based on data collected between October 2003 and September 2004, supplemented with older migrated data from September 2000 through September 2003. Active pumping in the transport model is simulated to begin in June 2005. Several pumping strategies were simulated that assumed the first year of active pumping would operate at a combined flow rate of 200 gpm or less. For several of these strategies after the first year of pumping, the flow rate is increased for the duration of the simulation. Other scenarios assume continuous uniform pumping rates. Discussion of scenario results in Sections 5.1.4.2 through 5.1.4.5 is limited to those scenarios that are generally representative of the various scenario testing and results for each contaminant. RDX results are presented first followed by perchlorate simulation results.

Each model scenario was evaluated based on achieving the remedial action objectives. As noted in Section 4.4, the remedial action objectives are management of plume migration, contaminant mass removal and protection of downgradient public water supply well WS-2.

5.1.4.2 J-2 Range RDX Transport Scenarios

The model predicts the RDX plume will be remediated more quickly than the perchlorate plume due to the much larger geometry of the perchlorate plume and the fact that a greater portion of the perchlorate plume is situated in (or migrating into) low conductivity silts. Testing indicated that the RDX plume could be captured with approximately 90 gpm. This flow rate is considerably greater than the calculated cross sectional flux across the footprint of the J-2 RDX plume, approximately 15.2 gpm. The cross sectional flux across the footprint of the J-2 perchlorate plume (calculated at the plume's greatest width) is closer to 50.1 gpm. Simulations indicated that a single well system pumping at approximately 90 gpm would capture a significant portion of the RDX plume and address considerable perchlorate mass.

Transport of the RDX plume with the existing MMR remedial systems operating under average conditions, but indicates no J-2 systems operating (a no action scenario) indicates the plume attenuates below the HA of 2 µg/L within 7 years (Figure 5-10a, Figure 5-10b, and Animation 5-1). Of the 0.80 kg of RDX mass initialized in the model, 0.56 kg remains in the model at the end of the 30-year simulation. Of the remaining 0.24 kg, 0.10 kg is captured by public water supply well WS-2 and 0.14 kg exits the model boundary. Additional discussion of WS-2 is below. The model indicates the plume does not appreciably migrate downgradient in concentrations above the HA under ambient conditions.

With active pumping, the RDX plume is remediated in a similar timeframe to the no-action scenario. Figure 5-11 shows the mass capture percentages for a number of one, two and three-well scenarios. Although there is a 13 percent difference in total mass capture between the one-well scenario and the best three-well scenario, each of these scenarios performs very similarly in terms of the migration of plume concentrations above the HA. In each case, the plume does not migrate downgradient in concentrations above the HA, and attenuates in place. There is insufficient mass within the aquifer to overcome the affects of dispersion and therefore, the plume cannot migrate appreciably downgradient.

Public water supply well WS-2 is situated downgradient of the J-2 North plume. WS-2 is screened from approximately 107 ft. to 127 ft. depth below ground surface and -53 to -73 feet msl. The well is permitted at 1.5 mgd; however, the actual annualized average flow rate is 0.246 mgd. To assess the potential interaction of the J-2 North plume and WS-2, a series of simulations were conducted using the groundwater flow model. The ZOC (the 3D region in the aquifer yielding water to the well) was determined using particle back tracking from the supply well screen interval. The ZOC was determined at flow rates equal to the average daily flow and the maximum permitted flow rate. In addition, forward particle tracking was conducted from known detections within the body of the plume as compared to the ZOC for the supply well. Lastly, fate and transport of the J-2 North plume was evaluated under ambient (no pumping from the WS-2) and with WS-2 pumping at average operating flow rates. The results indicate that the ZOC for WS-2 intersects the top of the J-2 North plume. Forward particle tracking suggests that particles representative of the top of the plume would likely be captured by the supply well. Transport results indicate that low levels of perchlorate would be expected in the well at very low concentrations. Maximum concentrations likely to be observed in the supply well, if the plume was left unremediated, would approach 0.015 µg/L of RDX and 0.62 µg/L of perchlorate. The ZOC for WS-2 under average operating and maximum permitted flow rate is shown on Figure 1-3, Figure 1-4, Figure 2-1a and Figure 2-1b. None of the current monitoring wells or sentry wells for WS-2, located near and north of Gibbs Road, indicate the presence of contamination associated with the J-2 Range above method detection limits.

Modeling indicates that low concentrations of perchlorate, at concentrations of 0.025 µg/L, may migrate to sentry well C7 (C7 is located along Gibbs Road near the predicted centerline of the plume) in the future under the designed wellfield. There are two other area water supply wells in the vicinity of WS-2; WS-3 and WS-1, situated west and east of WS-2, respectively. These wells operate at similar flow rates as WS-2. Modeling indicates that the J-2 North plume will not migrate near the contributing areas or the ZOCs to these two supply wells.

5.1.4.3 Proposed Wellfield RDX Modeling Results

For Scenario 25g_u, the recommended strategy, RDX concentrations fall below the HA within 6.5 years with no significant downgradient migration of the plume (Figure 5-12a, Figure 5-12b, and Animation 5-2). This result is similar to the simulations of other no-action and one, two and three-well strategies. Approximately 0.62 kg of RDX is captured by extraction well J2EW0001 and 0.11 kg is captured by J2EW0002, for a total of 0.73 kg. This indicates that 84% of the mass captured in Scenario 25g_u is captured by the upgradient well, closest to the center of the plume mass. The other 0.07 kg remains in the model at the end of the simulation. Water supply well WS-2 does not capture a statistically significant mass of RDX. Additional description of the well and infiltration trench locations and flow rates for Scenario 25g_u are presented in Section 5.5.

Because of the proximity of the proposed J-2 North pumping to the J-1 and J-2 East plumes, an evaluation of potential impacts on these plumes' trajectories was conducted. In order to develop capture zones, the aquifer has to be sufficiently stressed to direct flow within the plume geometry toward the extraction wells. However, this necessary stress can also have adverse affects on neighboring plumes such as changes in plume trajectory or plume smearing. The impact of the stressed flow field near the J-1 and J-2 East plumes was assessed by evaluating the model-predicted drawdown and mounding under stressed conditions reflective of the wellfield design pumping stress. The model-predicted drawdown was calculated for the model layer corresponding to the approximate elevations of the J-1 and J2 east plumes (model layer 14). The extent of the model-predicted hydraulic influence indicates that the pumping stress at J-2 North is not sufficient to detrimentally affect the J-1 or J-2 East plumes (Figure 5-13).

No sensitive surface water bodies were identified in the vicinity of the J-2 North plume, and therefore, no assessment of ecological thresholds (e.g., drawdown, changes in flux, etc.) was necessary.

Maximum model-predicted influent RDX concentrations for Scenario 25g_u were 0.42 µg/L, 0.09 µg/L, and 0.002 µg/L in extraction wells J2EW0001, J2EW0002 and J2EW0003, respectively. The maximum blended concentration for the three wells is 0.23 µg/L. The maximum model-predicted influent RDX concentrations in water supply well WS-2 was 0.000035 µg/L. Modeling indicates that very low concentrations (0.0024 µg/L) of RDX may migrate to sentry well C4 (C4 is located along Gibbs Road east of the predicted centerline of the plume), in the future under the designed wellfield.

The wellfield design for Scenario 25g_u meets the remedial action objectives as outlined in Section 4.2.3 with regards to the J-2 RDX plume. The plume does not migrate significantly downgradient in concentrations above the HA and approximately 91% of the plume is captured. The scenario is also protective of water supply well WS-2.

5.1.4.4 J-2 Range Perchlorate Transport Scenarios

Perchlorate transport modeling included simulation of a no-action scenario with the existing MMR remedial systems operating under average operating conditions, and cases with active remediation of the perchlorate plume. In addition, testing of the plume remediation with a hypothetical continuing source term was conducted.

Under the no-action scenario (average operating conditions for the MMR remedial systems, but no J-2 remediation), the transport model predicts the J-2 perchlorate plume migrates toward and partially underflows water supply well WS-2 (Figure 5-14a, Figure 5-14b and Animation 5-3). The plume then continues toward Upper and Lower Shawme Ponds, which serve as major discharge areas for groundwater in this portion of the aquifer and control local gradient direction. The plume reaches Upper Shawme Pond in concentrations between 1 and 5 µg/L after approximately 38 years. The maximum model predicted influent concentration under the no-action scenario in WS-2 is 0.62 µg/L at year 2031.

The initial active remediation scenarios (1-7) mostly used a two-well configuration and total flow rate of 175 gpm (Table 5-5). Scenario 7b had the best performance in terms of mass capture of these early scenarios and was the basis for several later scenarios (Figure 5-15a, Figure 5-15b and Animation 5-4). This scenario featured two extraction wells in an axial configuration, with the wells spaced to maximize their area of influence while remaining near the higher concentration areas of the plume.

Subsequent runs focused on three-well strategies with higher flow rates. Testing indicated that focused extraction closer to the core of the plume while allowing a portion of the leading edge of the plume to attenuate resulted in greater mass capture and a shorter restoration timeframe (Figure 5-9). This is illustrated in the predicted influent concentrations in WS-2 for Scenario 17b, a scenario with downgradient extraction well J2EW0003 positioned downgradient of the leading edge of the plume and operating at 100 gpm. The maximum influent concentrations for Scenario 17b are nearly identical to those predicted for Scenario 25g_u which has a leading edge well situated within the plume footprint (both approximately 0.032 µg/L). However, restoration timeframes are extended in Scenario 17b, with greater than 1 kg more perchlorate mass remaining in the aquifer compared to Scenario 25g_u at year 2013. Total mass capture for the scenarios is similar (27.3 kg in Scenario 17b vs. 27.4 kg in Scenario 25g_u), although the rate of mass capture is greater in Scenario 25g_u for the first 20 years of the simulation. This testing indicates that compared to in-plume extraction, downgradient extraction (downgradient of the leading edge of the plume) results in similar total mass capture, extended restoration timeframe and nearly identical performance regarding protection of water supply well WS-2.

For several of the later scenarios (including the recommended scenario - Scenario 25g_u), infiltration trenches were moved closer to the edge of the plume with no significant change in system capture performance. Additional discussion of Scenario 25g_u is included in Section 5.5.

Sensitivity testing of the perchlorate plume and extraction well screen intervals was conducted using Scenario 21 well locations and flow rates. The locations of the extraction wells and the flow rates and flow rate distributions in Scenario 21 are identical to those in Scenario 25g_u, with a slight difference in the location of the downgradient extraction well J2EW0003. As described in Section 5.1.3.3 and 5.1.5, expanded mass and expanded volume plume shells were used for uncertainty testing. The expanded mass plume shell is characterized by increased aerial extent of the higher concentration core of the plume from monitoring well MW-289 to Wood Road and the expanded volume plume shell featured increased volume along the edges of the plume by placing low-concentration control points in these areas and increasing the size of the mask used during the kriging process. The expanded mass plume shell had 53.1 kg of mass (compared to 29.5 kg for the base case plume shell). The maximum concentration in the expanded mass plume increased to 450 µg/L, compared to 370 µg/L in the base case plume shell. Total mass of the expanded volume plume shell was 29.7 kg, slightly higher than the base case plume shell. The maximum concentration was the same as the base case plume shell.

Transport results indicate that using the system configuration from Scenario 21b and the mass-expansion plume shell, approximately 95.7% of the plume is captured (compared to 96.1% of the base case plume). The maximum influent concentration in water supply well WS-2 is 0.025 µg/L. Graphics of model-predicted concentrations show the plume does not migrate significantly downgradient of its initial position (Figure 5-16a, Figure 5-16b and Animation 5-5). Using the expanded volume plume shell, total mass capture is 93.7% and plume migration behavior is similar (Figure 5-17a, Figure 5-17b and Animation 5-6). The maximum influent concentration in water supply well WS-2 is 0.027 µg/L. The results of the plume shell sensitivity testing indicate the remedial system flow rates and well locations are appropriate for addressing uncertainty related to the plume configuration and concentration magnitudes.

Sensitivity testing of reinjection wells vs. infiltration trenches, and variations on trench locations, was conducted in Scenarios 2 and 21. Testing was conducted in Scenario 2 of both reinjection wells and infiltration trenches, and also removing the reinjection stress completely away from the area. Using reinjection wells along both Wood and Jefferson Roads resulted in only 0.2% additional mass capture compared to infiltration trenches along Wood Road only. Moving the infiltration trenches from Wood Road to Jefferson Road reduced mass capture by another 0.2% and removing the infiltration stress completely reduced capture by an additional 1.3%. In Scenario 21, treated water from extraction well J2EW0002 was shifted from the Jefferson Road trenches to the Wood Road trenches. This change in stress resulted in a 0.1% decline in capture. The testing indicates that there is virtually no difference in capture performance using either infiltration trenches or reinjection wells.

Variations of screen interval locations or lengths were tested in Scenario 21e for improved mass capture (Figure 5-18). Scenario 21e_ns tested different screen location (same lengths as Scenario 21e) while in scenario 21e_ns2 screen lengths were shortened by 1/3 compared to the first two simulations. Transport results indicate plume capture is insensitive to these changes in screen position or length (Figure 5-18).

Flow rate sensitivity was evaluated based on a chart of mass capture versus flow rate for all of the tested scenarios (Figure 5-19). The graph indicates that increase in perchlorate mass capture diminishes near the group of 375 gpm scenarios, with only slight increases in mass capture for the higher flow rate scenarios. This, along with animations of plume migration and predicted effects on WS-2, indicates that a flow rate of 375 gpm is appropriate for the system.

Although the highest observed concentrations in the J-2 North plume are disconnected from the source area, there have been recent perchlorate detections in nearby wells, such as MW-130 and MW-234. Testing of the potential effects of a continuing source was conducted using well locations and flow rates from Scenario 21g. The continuing source concentrations were introduced into the model through the MODFLOW recharge package. As a conservative approach, the source was designed to introduce concentrations of greater magnitude than recent detections near the source area. The simulated source was active in the simulation for the first six years, declining in strength from 500 to 100 µg/L per cell (in 7 total cells). The cells used for source concentrations correspond to the entire geophysical polygon footprint surrounding Disposal Area 2 (Figure 1-2). Transport results indicate the upgradient well (J2EW0001) captures the additional mass emanating from the source area and the continuing source does not result in a significant increase in remediation timeframe (Figure 5-20a, Figure 5-20b and Animation 5-7).

5.1.4.5 Proposed Wellfield Perchlorate Modeling Results

As noted in Section 5.1.4.3, Scenario 25g_u was determined to be the most effective wellfield to meet the design objectives. Scenario 25g_u includes three extraction wells: a well located approximately 550 feet south of the intersection of Wood and Barlow Roads, a second well situated approximately 900 feet north of the intersection of Wood and Barlow Roads, and a third well located approximately 600 feet north of the intersection of Jefferson and Barlow Roads (Figure 5-21). A total flow rate of 375 gpm: 75 gpm from the upgradient well, 175 gpm from the well situated between Wood and Jefferson Road, and 125 gpm from a leading edge well was determined to be the most efficient distribution of flow rate. Reinjection/infiltration testing indicated that infiltration trenches are as effective as reinjection wells. Infiltration trenches situated lateral to the plume are proposed as components of the final design. The trenches are located along existing roads; two are situated along Wood Road (one east and one west of the plume footprint), and two are located along Jefferson Road (one east and one west of the plume footprint). The proposed extraction well construction details are presented in Table 5-6. As noted in Section 5.1.4.2, the plume flux (the total flow across the widest portion of the perchlorate plume) is approximately 50.1 gpm, and therefore, the proposed rate is very conservative.

Perchlorate transport under the proposed Scenario 25g_u indicates that the wellfield effectively captures most of the upgradient perchlorate mass (Figure 5-22a, Figure 5-22b and Animation 5-8), with some mass remaining in low conductivity units at the end of the simulation. Approximately 27.4 kg (92.7%) of the perchlorate plume is captured in Scenario 25g_u after 30 years, while approximately 1.75 kg of perchlorate remains in the model at the end of the simulation. It is important to note that of the perchlorate initialized in the model, a small portion of the plume (0.85 kg) is initialized in very low conductivity units and additional mass is located near the bottom of the aquifer in low conductivity units that is not feasible to remediate. More than 90% (26.6 kg) of the plume mass is captured by year 2020.

Maximum model-predicted influent perchlorate concentrations for Scenario 25g_u were 40.1, 28.7 and 3.0 µg/L in extraction wells J2EW0001, J2EW0002 and J3EW0003, respectively. The maximum blended concentration for the three wells is 33.6 µg/L. Modeling indicates that with the proposed RRA system implemented, low concentrations (0.25 µg/L) of perchlorate may migrate to sentry well C7 (C7 is located along Gibbs Road near the predicted centerline of the plume); however, the maximum model-predicted influent perchlorate concentrations in water supply well WS-2 is 0.031 µg/L at year 2019.

The wellfield design for Scenario 25g_u meets the remedial action objectives as outlined in Section 4.2.3 with regards to the J-2 perchlorate plume. Downgradient plume migration is minimized while focused in-plume extraction reduces high concentration areas of the plume and reduces the restoration timeframe. Approximately 92.7% of the base case plume is captured and WS-2 is protected.

5.1.5 Uncertainty

Although groundwater modeling serves as an important tool for evaluating hydrogeologic systems, no model can address the full range of complexities present in such systems. Therefore, although a calibrated groundwater model may represent the best technical attempt at matching the model results to observed conditions, the model solution represents only one of many combinations of conditions and physical parameters that could provide equally valid calibration matches. The uncertainties inherent in such evaluations has been greatly reduced at MMR owing to the large data set based on numerous investigations, and the constant model validation and calibration checks each model is subjected to.

Physical hydrogeologic parameters, such as K and effective porosity, vary spatially depending on geologic characterization of the aquifer systems. These spatial variations, often referred to as aquifer heterogeneities, generally cannot be quantified adequately during data collection efforts. As a result, estimates of aquifer parameters always contain a degree of uncertainty.

The rate of recharge is also an area of uncertainty. An average rate of recharge of 32 inches per year is necessary to sustain groundwater elevations for the K field within the 2001 AFCEE regional model. However, the calibration of recharge does not produce a unique model solution. Similar groundwater elevations could be achieved with a lower recharge rate by decreasing the transmissivity of the aquifer (e.g., increasing the thickness of the basal silt at the bottom of the model or decreasing horizontal K), increasing anisotropy (i.e., decreasing vertical K), or by restricting outflow at the model boundaries by reducing the conductance terms that allow water to flow through the boundary. A higher modeled recharge rate would indicate that more groundwater is available for development within the safe yield of the aquifer and that higher flow rates are required to capture a plume. A higher recharge rate would also cause plumes to become deeper with time as clean water from recharge accumulates on top of the plumes. In terms of modeling, this affects the placement of well screens to either monitor or extract contaminants over long-time periods and required flow rates to capture a contaminant plume.

Recharge and antecedent recharge conditions can influence the elevation and location of the top of mound (TOM). In addition, spatial variability in recharge on Cape Cod may play a role in small-scale perturbations in the water table configuration. Plume paths and rates of travel will vary somewhat with time as the water table fluctuates in response to precipitation and aquifer pumping. Due to its position near the TOM and the transient position and elevation of the mound, there is some uncertainty associated with the modeled and observed groundwater flow trajectory and gradient magnitude. While there is a good record of water level fluctuations, synoptic monitoring of western Cape Cod groundwater elevations suitable for calibrating groundwater models is more limited and only began in 1993. Assuming that the plumes originated from the SE Ranges in the 1960s, there is no record of average conditions for groundwater elevations during the first three decades of plume migration. The groundwater modeling approach used here attempts to address this uncertainty by (1) simulating a steady-state condition that is representative of average groundwater conditions, and (2) testing differing realizations of water table conditions. In this instance, the model was calibrated to data sets collected in 2000 and August 2003 when water levels were near their historical average. Plume trajectories are calibrated against observed detections by forward particle tracking from known source areas or backward particle tracking from detections to the water table.

Detailed information on the timing and nature of contaminant releases in the J-2 source area are limited. In addition, areas downgradient of the source area are still under investigation to further determine the extent and magnitude of groundwater contamination. As a result, the actual contamination related to the J-2 Range and other areas may differ from that simulated for this work. Backward particle tracking from known detections in groundwater samples to the water table has been used to confirm suspected source areas. Total plume mass has been used to estimate the time and rate of source release to the water table. These techniques reduce uncertainty in describing former and continuous source characteristics for contaminant plumes.

The actual performance of the remedial system will be dependent on the 3D distribution of K within the aquifer. The three principal components of the K tensor (K_{xx}, K_{yy}, and K_{zz}) control where water and contaminants flow within the aquifer and to the extraction wells. Larger values of K_{zz} (vertical K) increase the potential for capture of clean water above the extraction interval within the aquifer. As K_{zz} decreases, horizontal flow becomes more prevalent, and enhances the width of the capture zone achieved by the remedial system. It is not possible to conclusively determine the effect heterogeneous K fields will have on a remedial system until the system becomes operational; however, the development and calibration of the J-2 model has been conducted with the intent of bounding the range of expected behavior.

Quantification of dispersivity is a source of uncertainty. A range of dispersivities have been calculated for various hydrogeologic conditions at MMR and have been summarized. Dispersivities at MMR were originally calibrated for a boron plume emanating from sludge beds at the Ashumet Valley Wastewater Treatment Plant. The dispersivities were higher than those calculated by the USGS for tracer tests on a relatively small-scale research site at MMR. Calibration of dispersivities at the FS-1 plume site indicated smaller dispersivities than those calibrated originally for Ashumet Valley. The FS-1 site has a converging flow field where the contaminants discharge in bogs that act as groundwater sinks. Because most contaminant transport at MMR is controlled by advection due to the high groundwater velocities, modeling conducted by AFCEE after 2002 adopted the FS-1 plume site dispersivities. This resulted in most recent groundwater models using longitudinal, transverse and vertical dispersivities of 10, 0.3 and 0.03 feet, respectively.

5.2 TREATMENT SYSTEM BASIS OF DESIGN

This section presents the basis of design for the J-2 North groundwater treatment system. The selected treatment process (granular activated carbon, ion-exchange, and polishing granular activated carbon [GAC-IX-GAC]) is consistent with the technology currently employed at the Frank Perkins Road treatment plant and planned for the J-3 RRA to address identical COCs as are found in the J-2 North plume. The treatment train is discussed further in Sections 5.3 and 5.4. In addition to achieving the remedial action objectives and treatment standards, the selected treatment technology is designed to minimize total life cycle cost and training requirements for operations and maintenance (O&M) personnel. To support these objectives, lessons learned from other MMR treatment systems will be incorporated into the J-2 North groundwater design to the maximum extent possible.

5.2.1 Contaminants of Concern and Influent Concentrations

Based on the preliminary wellfield scenario testing, the maximum influent concentration of perchlorate from the three extraction wells is expected to approach 33.6 µg/L, with the maximum from any one extraction well approaching 40.1 µg/L. Although the maximum detected perchlorate concentration within the plume is much higher (140 µg/L), influent concentrations in extraction wells are typically much lower because the extraction wells are screened across both low and high concentration areas within plumes and the well captures low concentration areas outside the core of the plume. They inevitably capture some clean water that mixes with higher concentration water from discreet intervals along the extraction screen. The maximum influent concentration of RDX from the three extraction wells is expected to approach 0.23 µg/L, with the maximum from any one extraction well approaching 0.42 µg/L. The maximum detected RDX concentration within the plume is higher (11 µg/L).

5.2.2 Treatment System Media Change-Out

The J-2 North groundwater treatment system will require the use of treatment media (carbon and resin) that will periodically require replacement or change-out as the capacity for effective treatment within an individual treatment vessel becomes exhausted. The change-out criteria will be discussed in an O&M plan.

5.2.3 Biofouling Potential

A potential limiting factor on the treatment system is the possibility of biofouling. Selected physicochemical parameters and metals were analyzed to determine the likelihood for biofouling potential in the J-2 North well field. The J-2 North dataset included groundwater samples collected from 68 well screens (29 monitoring well locations) within the proposed J-2 North capture zone. Data considered in evaluating biofouling potential are presented in Table 5-7 and represent all available data collected that is reflective of groundwater within the modeled J-2 North capture zone.

To further evaluate the potential for biofouling of the J-2 North treatment system, groundwater samples were collected from well MW-300M2, which is located adjacent to

Wood Road between planned extraction wells J2EW0001 and J2EW0002. The samples were collected on 07 December 2004 and were analyzed for various chemical, physicochemical, and biological parameters. One water sample was collected prior to purging the well and a second after the well was purged for 3 hours. The pre-purge sample represents water that has stagnated within the well casing and the post-purge sample represents the aquifer. The results are summarized in Table 5-8.

Based on the data presented in Table 5-7 and Table 5-8, the potential for biofouling is considered minimal given the physical and chemical conditions in the vicinity of the monitoring wells evaluated. Specifically, the dissolved oxygen is at saturation conditions, there is minimal iron and manganese, and there is essentially no nutrient/carbon source available to support cellular activity. Therefore, biofouling should be absent.

5.3 TREATMENT TRAINS (GAC-IX-GAC)

The proposed treatment system consists of three extraction wells J2EW0001, J2EW0002, and J2EW0003 operating at 75, 175, 125 gpm respectively and four identical modular treatment systems, each capable of handling 100 gpm of water. The four modular treatment systems will be located at the intersection of Wood Road and Barlow Road (Figure 5-23). After passing through the pretreatment filter and the GAC-IX-GAC train, the treated water will be reintroduced to the aquifer through infiltration trenches (Figure 5-24). The trenches are to be located along existing roads. Two are to be situated along Wood Road and two along Jefferson Road.

The treatment process of GAC-IX-GAC is consistent with the technology currently employed at the Frank Perkins Road treatment plant and planned for the J-3 RRA to address identical contaminants as are found in the J-2 plume. The performance of these media is documented in several reports including: *Pilot Study Report for Treatment of Perchlorate in Groundwater EW-275 (Near MW-211M2),* (AMEC 2004c), and the rapid small scale column tests described in the *Draft Innovative Technology Evaluation Groundwater Treatability Study Summary: Rapid Small Scale Column Tests #1* (AMEC 2003a), and *Draft Innovative Technology Evaluation Groundwater Treatability Study Summary: Rapid Small Scale Column Tests #2* (AMEC 2004b). The results demonstrated that these treatment technologies are appropriate for the removal of perchlorate and RDX from groundwater at MMR.

GAC adsorption for RDX removal, IX resin for perchlorate removal, and a polishing GAC in the event of breakthrough has been demonstrated to reduce contaminant concentrations to required treatment levels. A presentation of the technology evaluation, treatment alternatives, and cost comparisons of this method versus other technologies is presented in the *Final J-3 Range Groundwater Rapid Response Action (RRA) Plan* (ECC 2005).

5.4 DESCRIPTION OF TREATMENT PROCESS

This section describes the pretreatment, RDX and perchlorate removal systems, and the GAC polishing system.

5.4.1 Pretreatment

The J-2 Groundwater plume influent will be pumped from the extraction wells to the treatment containers. The influent will first flow through a set of bag filters which will reduce any suspended solids in the influent and thereby reduce the suspended solids that enter the primary set of carbon filters. In addition, provisions can be made in the design to accommodate connection points for chemical addition should it be required in the future (e.g., for treating biofouling).

5.4.2 RDX Removal System

After pretreatment, the influent will be piped to the initial set of GAC vessels to remove RDX. The RDX GAC vessels will consist of two 1,000-pound vessels arranged in parallel, and will be pressure rated according to the design system pressure. The vessels will be filled with carbon to capture RDX. The GAC system will be equipped with the necessary interconnecting piping, valves, gauges, and pressure relief devices.

5.4.3 Perchlorate Removal System

After removal of RDX from the influent by the initial set of GAC vessels, a second set of vessels containing IX resin will remove the perchlorate present in the J-2 North groundwater. The IX vessels will consist of two 1,000-pound vessels arranged in parallel, and will be pressure rated according to the design system pressure. The IX vessels will also be equipped with the necessary interconnecting piping, valves, gauges, and pressure relief devices.

5.4.4 Polishing System

After flowing through the IX vessels, the groundwater will flow through a second set of GAC vessels. This step will function as a polishing set in the event of breakthrough of RDX from the primary set of GAC or perchlorate from the IX vessels. The polishing GAC vessels will consist of two 1,000-pound vessels arranged in parallel, and will be pressure rated according to the design system pressure. The polishing GAC system will be equipped with the necessary interconnecting piping, valves, gauges, and pressure relief devices. The lead GAC and the polishing GAC will be piped so that their positions are interchangeable. This will ensure that virgin carbon will be used in the polishing bed at all times.

5.5 PIPING

This section describes the piping systems that will be used to convey the extracted and treated groundwater. Piping for conveying extracted groundwater from the extraction wells to the treatment system will be buried below the ground surface. The treated groundwater (effluent) will be discharged using infiltration trenches. The following sections describe the influent and effluent piping systems.

5.5.1 Influent Piping

Approximately 3,600 feet of new single wall high-density polyethylene (HDPE) pipe will be installed from the three extraction wells (J2EW0001, J2EW0002, and J2EW0003) to the J-2 treatment facility. The influent header to J2EW0001, J2EW0002, and J2EW0003 is assumed to run parallel to Barlow Road to the J2 treatment facility. The influent header piping to the J-2 plant is expected to be approximately 2 to 6 inches in diameter.

5.5.2 Effluent Piping

The J-2 treatment facility effluent system header piping consists of 2-inch and 6-inch HDPE pipe. The length of header piping from the J-2 North facility to the furthest infiltration trench is approximately 3,200 feet. The treated groundwater from the J-2 North plume treatment system will be approximately 375 gpm.

The effluent header will run north and south along Barlow Road to Jefferson and Woods Roads, and will continue east and west on both roads to infiltration trenches. Two trenches will be located parallel to Jefferson Road and two parallel to Woods Road. A total of approximately 8,000 feet of pipe will be installed from the treatment facility to the four infiltration trenches.

5.6 REMEDIATION WASTE AND SECONDARY WASTE MANAGEMENT

Waste that is generated as a result of J-2 North remedial activities can be categorized as either remediation waste or secondary waste. Remediation waste is any uncontainerized material, media, or debris that is contaminated. The only remediation waste that is expected to be generated by the J-2 North RRA project is extracted groundwater, which will be treated.

Secondary waste includes containerized waste that may or may not be contaminated. Examples of secondary waste include spent treatment media (resin, activated carbon, etc.), waste sludge, and personal protective equipment (PPE). Secondary wastes are typically stored and transported in drums, boxes, or tanker truck. Spent treatment media will undergo waste characterization to determine the appropriate means of treatment and disposal. Waste sludge and PPE that are generated by J-2 North ETI system activities will also be characterized and disposed in accordance with environmental regulations.

5.7 ADDITIONAL DATA REQUIREMENTS FOR FINAL DESIGN

The following data requirements are necessary prior to completing the detailed design of the J-2 North ETI system:

- determination of availability and routing of electrical power; and
- selection of final locations for containerized systems, piping and associated infiltration galleries.

6.0 SYSTEM PERFORMANCE MONITORING

A System Performance Monitoring plan will be developed to identify the sampling and monitoring necessary during baseline, start-up and routine monitoring phases of the system operations. This section presents the plan contents.

6.1 TREATMENT PLANT PERFORMANCE MONITORING

Treatment plant monitoring focuses on the operation of the treatment plant, the extraction wells, infiltration galleries, well pumps and all associated piping. The system will include the appropriate levels of alarms and safety switches to allow for continual operation. The system will be installed with logic and analog controls to allow for off-site monitoring of select operational parameters.

A baseline monitoring event will be conducted prior to system start-up. The baseline event is intended to provide a comprehensive account of plume characteristics prior to the initiation of active remediation. This baseline event will also include sampling of the influent and effluent process water at the time of system start-up.

Routine operational monitoring will occur at agreed-upon locations after start-up, as well as operational monitoring of system influent and effluent characteristics. Sampling for COCs will be conducted at select locations within the treatment system components, including the extraction wells, combined influent (before treatment), effluent (after treatment) and between the initial and secondary treatment units, if applicable. During the start-up process, sampling will be conducted weekly for a month to verify mass removal and to assess initial trends in predicted influent contaminant mass characteristics. After the start-up process, the sampling will be conducted every two weeks for a month, and then monthly. These data will be evaluated to confirm treatment effectiveness. Data evaluation techniques will employ calculations of mass removal rates and time series analysis. It is also expected that statistical analyses will be used to aid in the optimization of performance monitoring.

6.2 HYDRAULIC CONTROL MONITORING

Groundwater elevations will be monitored to assess the hydraulic effects of the extraction and infiltration systems and their characteristics relative to model prediction, and observed influence on the aquifer and plume characteristics. Groundwater elevations will be used to estimate horizontal and vertical gradients, to create groundwater flow maps and as input to recalibrate the groundwater model to verify capture of the plume. The System Performance Monitoring plan will include the rationale, location and depths for monitoring wells to perform adequate hydraulic control monitoring.

Start-up hydraulic monitoring will consist of collecting water level measurements from a range of locations related to J-2 North plume treatment prior to the onset of pumping to obtain information that is unaffected by operational stress. During start-up, water levels will be measured frequently at select locations near the extraction and reinjection areas. The data will be used for a distance-drawdown evaluation to assess capture, and to provide updated information on aquifer K and transmissivity. These data, in turn, will be used for model validation and refinement, and capture demonstration.

After the baseline hydraulic assessment is completed, hydraulic monitoring will be limited to periodic water level monitoring at selected wells and surface water locations in a subregional (plume-specific) synoptic network. These data will be used periodically to verify flow model predictions and evaluate trends due to ambient hydraulic stresses (e.g., recharge, private and municipal extraction) and any revisions to pumping rates in the J-2 North treatment system.

6.3 PLUME MONITORING

Groundwater monitoring for explosives and perchlorate will be conducted in a suite of monitoring wells designated specifically for ETI performance monitoring. This will provide an opportunity to evaluate changes in the nature, extent, and concentration of contaminants in the plume. Monitoring outside the plume boundaries at select well locations will be used to document that the plume has not moved beyond its original boundary during system operation, or migrated outside the expected plume trajectory or capture zone. This will include lateral extent monitoring as well as downgradient plume monitoring so that reductions in plume mass, volume, and geographic extent can be monitored. Trend analyses will be performed to evaluate overall changes in plume mass and dynamics.

6.4 ECOLOGICAL IMPACT MONITORING

No critical environmental habitats are expected to be impacted. No surface water bodies are located in the vicinity, overlying, cross-gradient or immediately downgradient of the J-2 North plume. No ecological impacts are expected and no ecological impact monitoring is required.

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7.0 IMPLEMENTATION

A number of important considerations govern the initiation of the major activities involved in the implementation schedule for the J-2 North groundwater RRA. This section discusses several of those implementation considerations. Major activities are:

- property access/environmental assessment (in progress);
- system engineering/design (in progress);
- system procurement (in progress);
- RRA implementation; and,
- performance monitoring.

7.1 PROPERTY ACCESS AND PERMITTING

The system is located entirely on MMR. No off-base property access issues are anticipated.

The environmental assessment process for the project addresses cultural and natural resource impact considerations. The pre-construction components of these efforts have been initiated and are expected to be completed by the time this RRA Plan is approved. Additional cultural resource assessments, if required, will be conducted during the trenching activities associated with pipeline installation for the in-plume extraction well.

7.2 SYSTEM DESIGN AND ENGINEERING

System design and engineering is ongoing and is expected to be finalized by the time this RRA Plan is approved.

7.3 PROCUREMENT AND CONSTRUCTION

Procurement of portions of the RRA system is presently underway. Contracting for RRA construction and implementation will be initiated after RRA plan approval.

7.4 RRA IMPLEMENTATION

Implementation of the RRA plan is estimated to take approximately ten months after the contract is awarded. Initial activities will focus on fabrication of the remaining treatment facilities, drilling of new extraction wells, placement of the vaults, installation of pipeline, and construction of infiltration trenches.

7.5 PERFORMANCE MONITORING

A System Performance Monitoring plan will be developed and submitted for agency concurrence. This plan will address performance monitoring activities, data analysis, system assessment, design verification, operational optimization, and reporting.

8.0 REFERENCES

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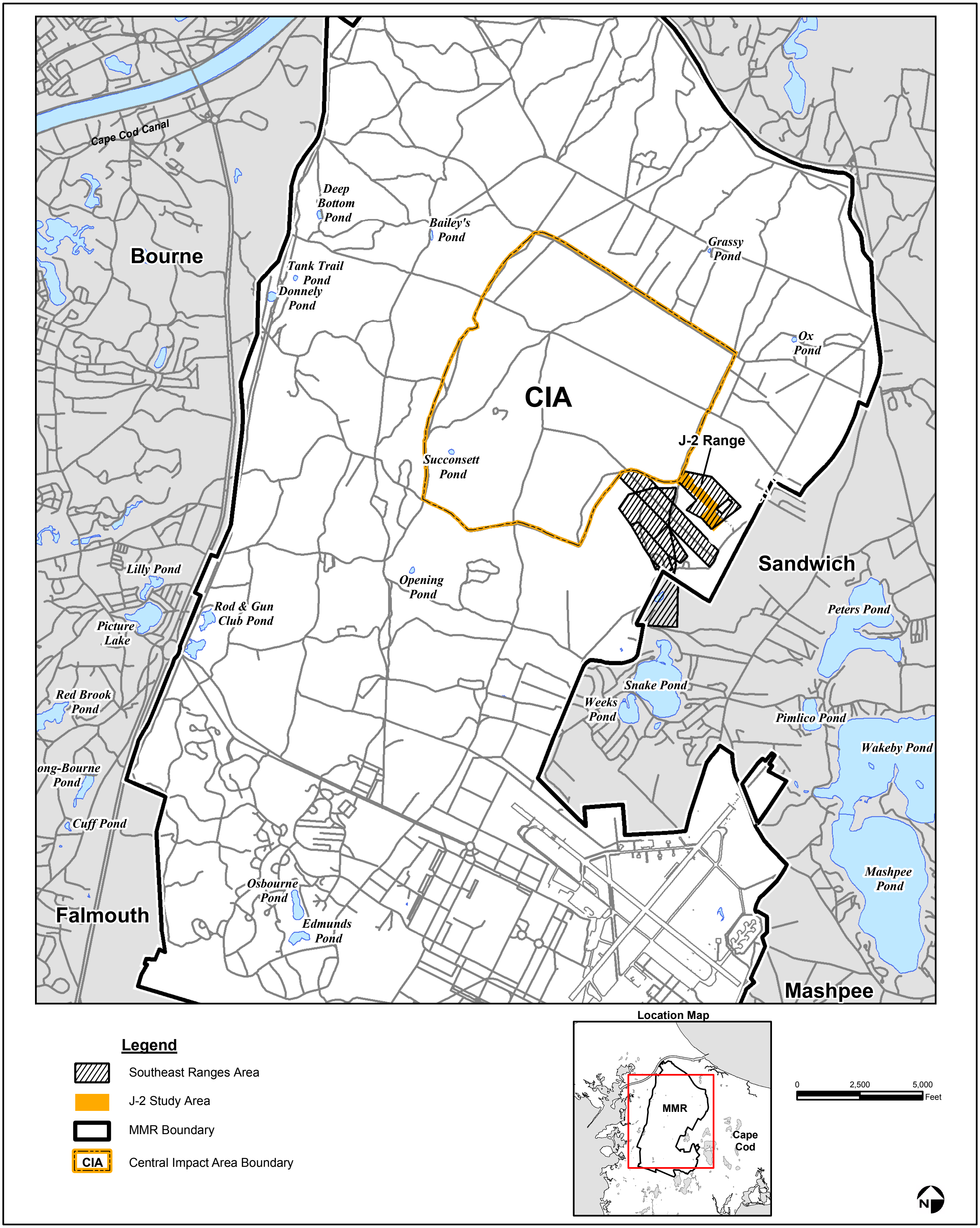
FIGURES



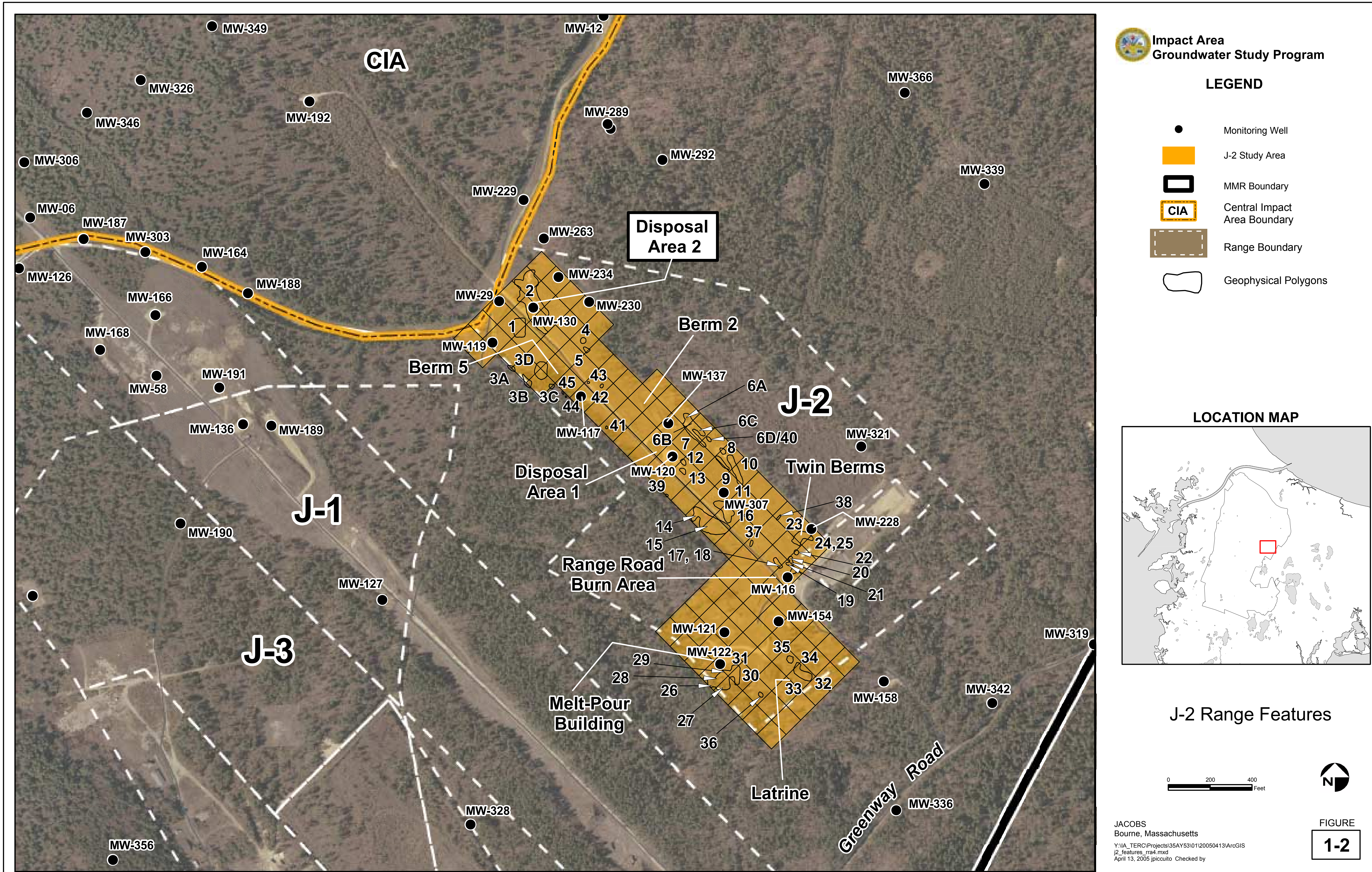
Location of J-2 Range Study Area

FIGURE
1-1

JACOBS
Bourne, Massachusetts

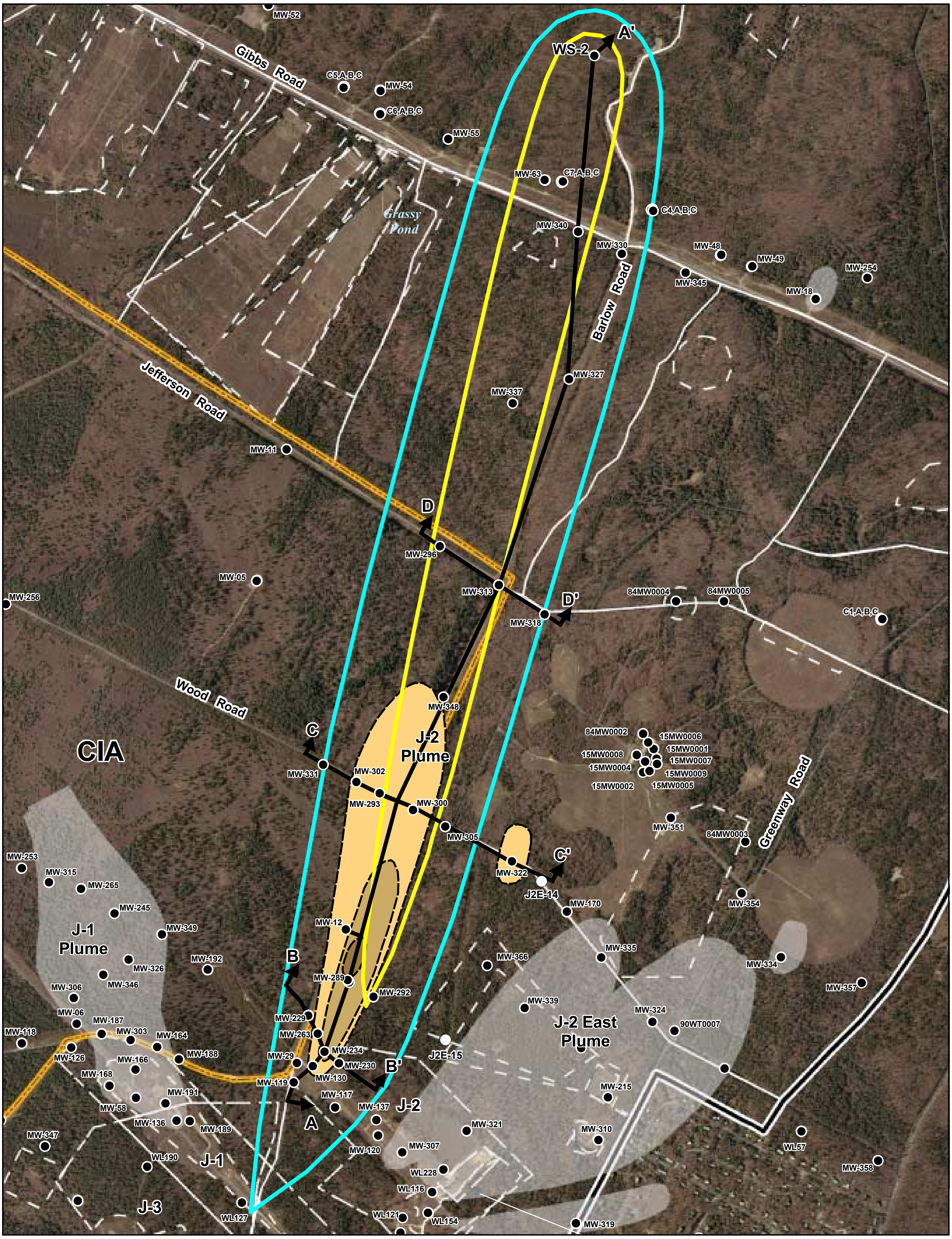
JACOBS
Bourne, Massachusetts
March 30, 2005 jpiccuito Checked by

Impact Area
Groundwater Study Program



J-2 Range Features

FIGURE 1-2



LEGEND

- ● Monitoring Well
- ○ Proposed Monitoring Well
- B —— B' Line of Cross Section

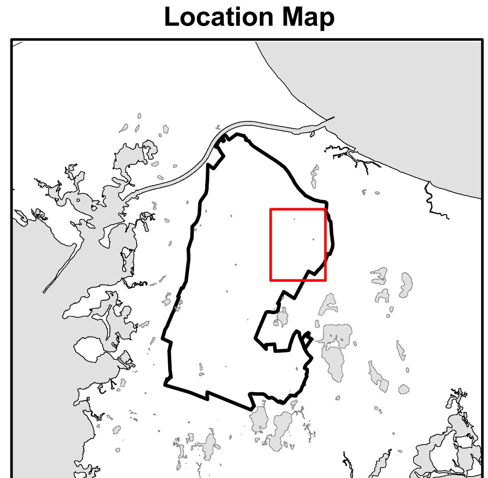
Zone of Contribution for Water Supply Well 2

- Average Operating Flow Rates
- Maximum Flow Rate (One Million Gallons/Day)
- MMR Boundary
- CIA: Central Impact Area Boundary
- Range Boundary

RDX Detection

- Non-detect to 2 µg/L
- 2-10 µg/L
- Greater than 10 µg/L
- J-1 and J-2 East Plumes

Location Map



0 512.5 1,025
Feet

N

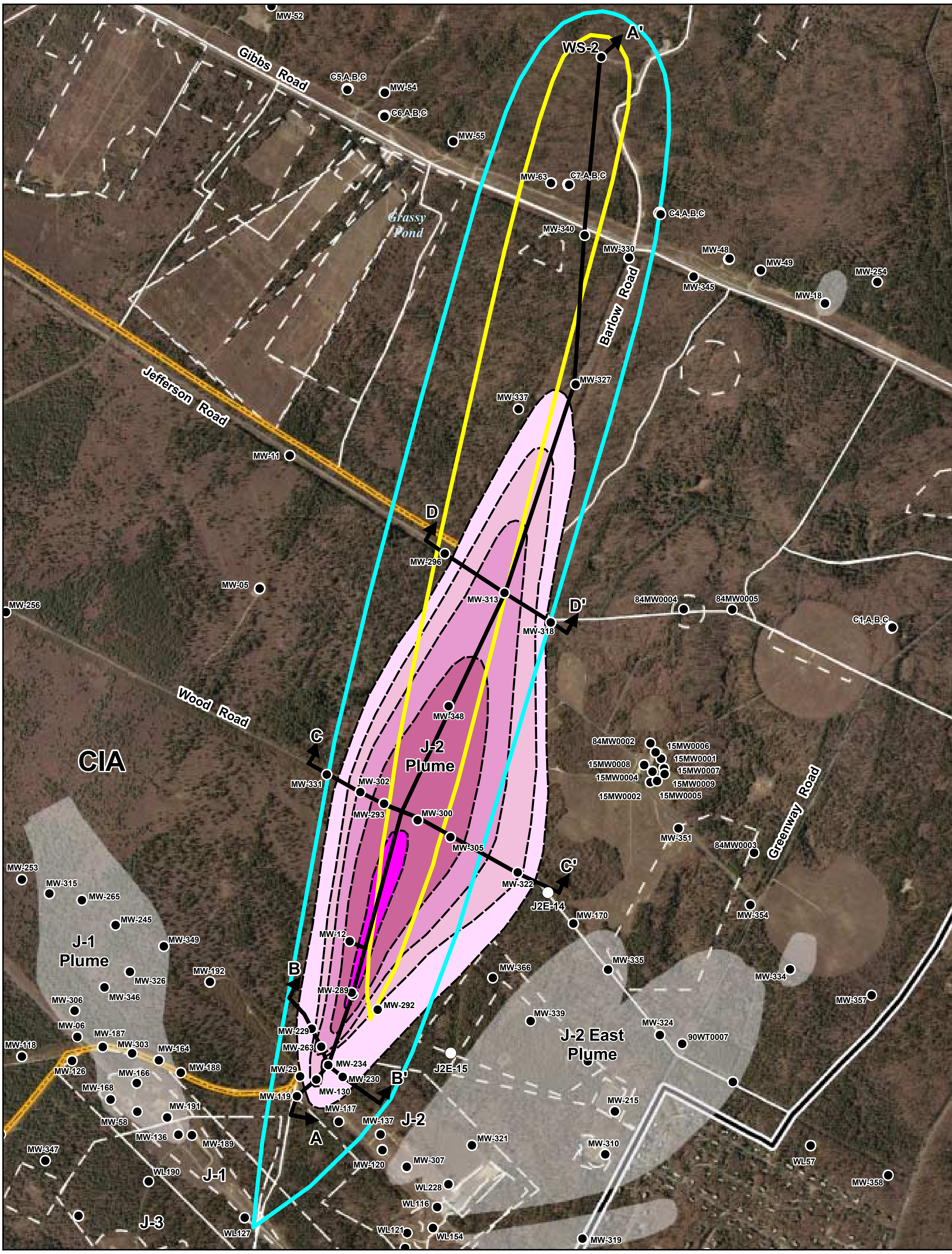
JACOBS
Bourne, Massachusetts

J-2 North Plume RDX Distribution and Lines of Cross Section Locations

FIGURE
1-3

JACOBS
Bourne, Massachusetts
Y:\IA_TERC\Projects\35AY53\01\20050419\ArcGIS
j2_rdx_plume_cross_section041905.mxd
April 19, 2005 jpiccuito Checked by

Impact Area Groundwater Study Program



LEGEND

- Monitoring Well
- Proposed Monitoring Well
- B — B' Line of Cross Section

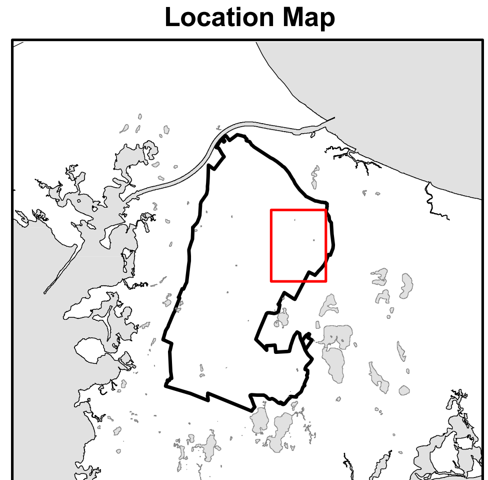
Zone of Contribution for Water Supply Well 2

- Average Operating Flow Rates
- Maximum Flow Rate (One Million Gallons/Day)
- MMR Boundary
- CIA — Central Impact Area Boundary
- Range Boundary

Perchlorate Detection

- Non-detect to 1 ppb
- 1-4 ppb
- 4-18 ppb
- 18-100 ppb
- Greater than 100 ppb
- J-1 and J-2 East Plumes

Location Map



0 512.5 1,025 Feet

N

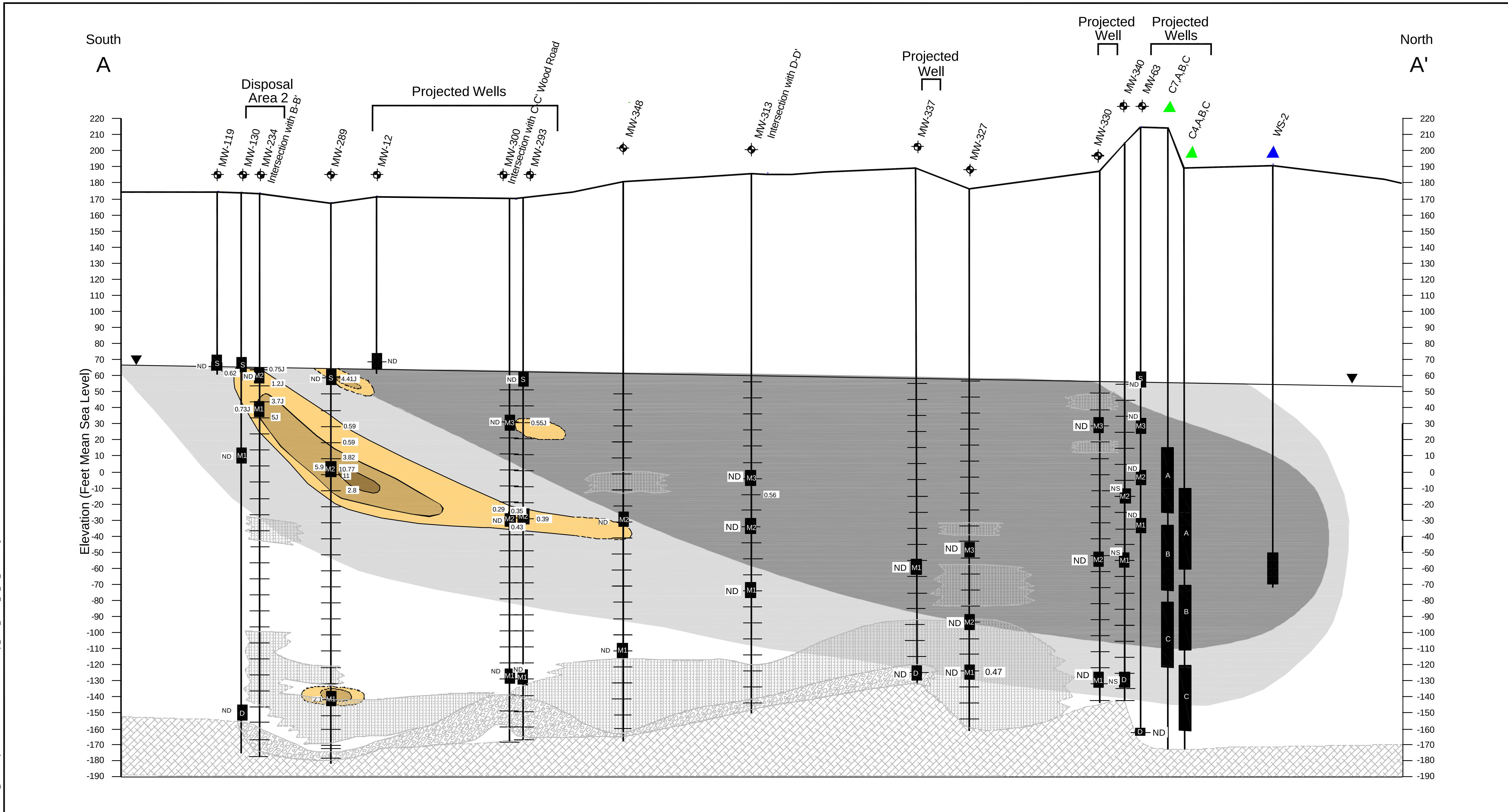
J-2 North Plume Perchlorate Distribution and Lines of Cross Section Locations

FIGURE **1-4**

JACOBS
Bourne, Massachusetts

JACOBS
Bourne, Massachusetts
Y:\IA_TERC\Projects\35AY53\01\20050519\ArcGIS
j2_per_plume_cross_section041905.mxd
April 19, 2005 jpiccuito Checked by

Impact Area Groundwater Study Program



Y:\IA_TERC\Projects\35AY53\01\20050330\AutoCAD\j2_cross_section_aa_rdx_033005.dwg

last modified: 03/30/05 printed: 03/30/05 by jp

Legend

Monitoring Well	
Water Supply Sentry Well	
Water Supply Well	
Water table	
M1	Well screen ID

Drilling Profile Interval Data (µg/L)

2

NS	Not Sampled
DL	Detection Limit
J	Estimated Concentration
ND	Nondetect
*	Unvalidated Data
µg/L	Micrograms per liter

Sand

Sand and Silt/Clay

Basal Gravel/Sand

Bedrock

Geologic Contact and Isoconcentration Contour (dashed where inferred)

Nondetect to 2 µg/L

2-10 µg/L

Greater than 10 µg/L

Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.

Zone of Contribution
Water Supply Well WS-2 (looking west)

Average Operating Flow Rates

Maximum Flow Rate (One Million Gallons/Day)

0

V: 60
H: 1000

Scale in Feet

Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.

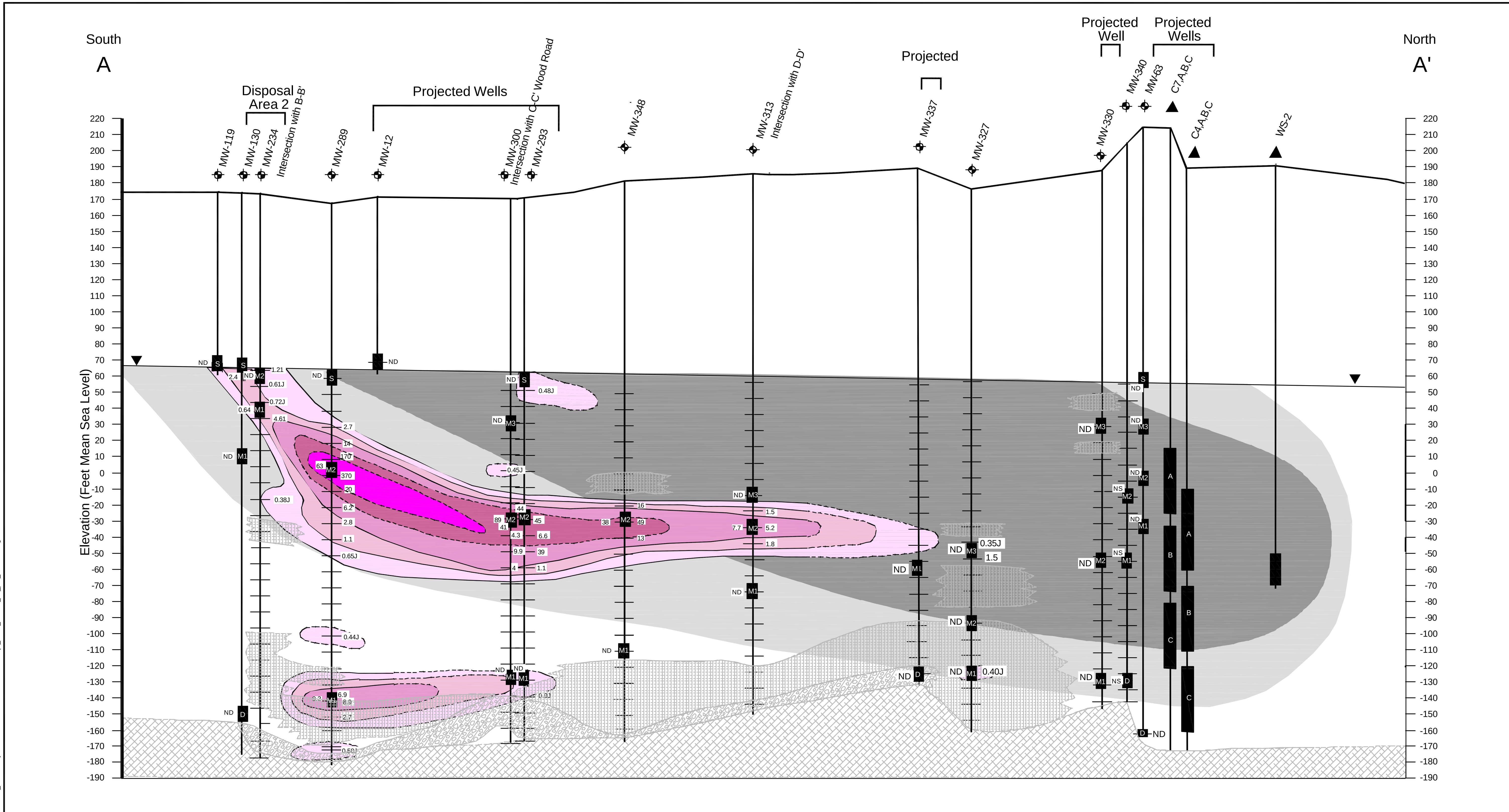
Impact Area Groundwater Study Program

J-2 North Cross Section A-A'
RDX Distribution

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP j2_cross_section_aa_rdx_033005.dwg

Figure 2-1a



Legend

	Monitoring Well
	Water Supply Sentry Well
	Water Supply Well
	Water table
M1	Well screen ID

Drilling Profile Interval Data (µg/L)

2

NS	Not Sampled
DL	Detection Limit
J	Estimated Concentration
ND	Nondetect
*	Unvalidated Data
µg/L	Micrograms per liter

Sand

Sand and Silt/Clay

Basal Gravel/Sand

Bedrock

Geologic Contact and Isoconcentration Contour (dashed where inferred)

Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.

Nondetect to 1 µg/L

1-4 µg/L

4-18 µg/L

Greater than 18 µg/L

Greater than 100 µg/L

Zone of Contribution
Water Supply Well WS-2 (looking west)

Average Operating Flow Rates

Maximum Flow Rate (One Million Gallons/Day)

0

V: 60
H: 1000

Scale in Feet

Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.

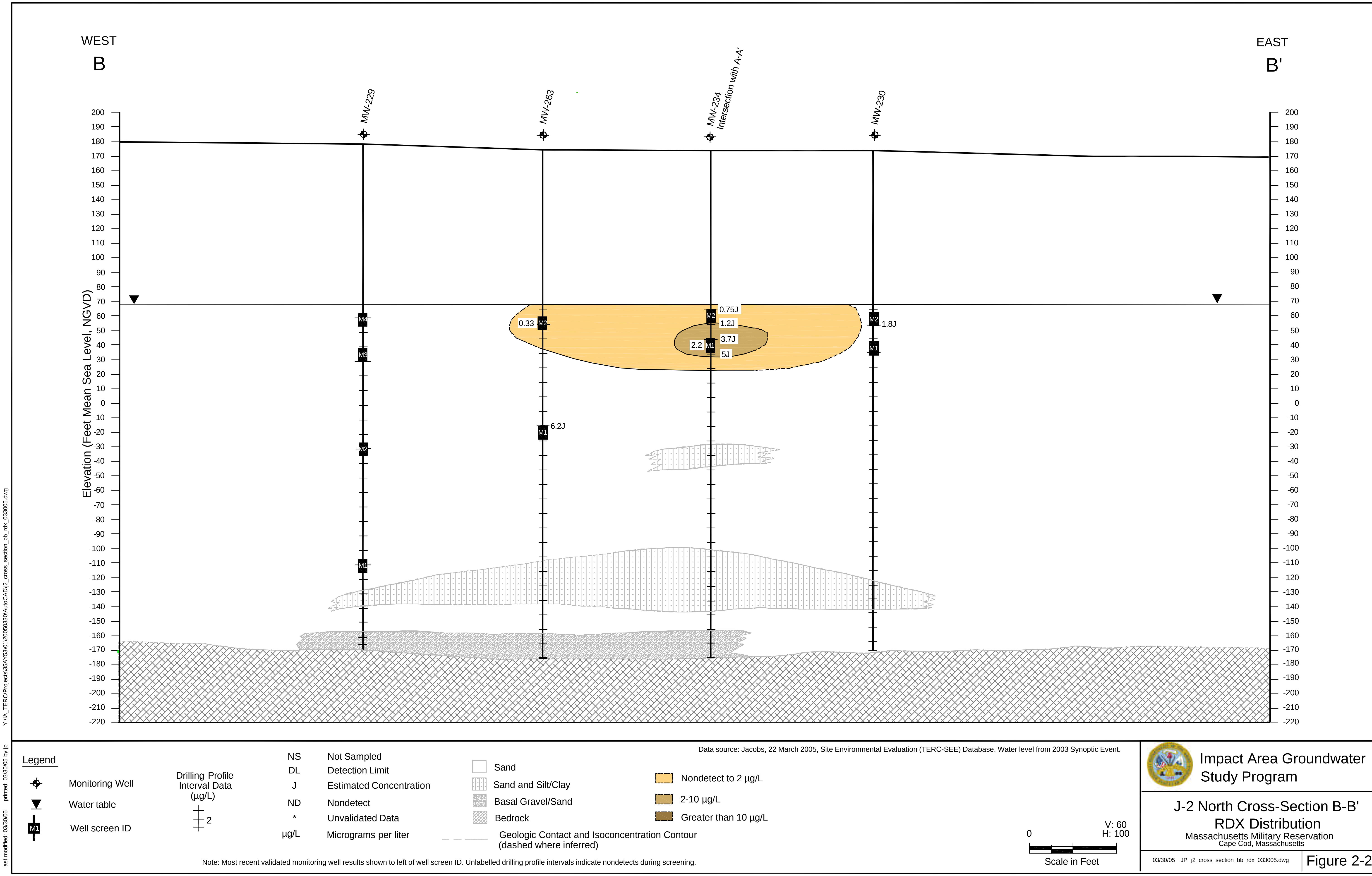
Impact Area Groundwater Study Program

J-2 North Cross Section A-A'
Perchlorate Distribution

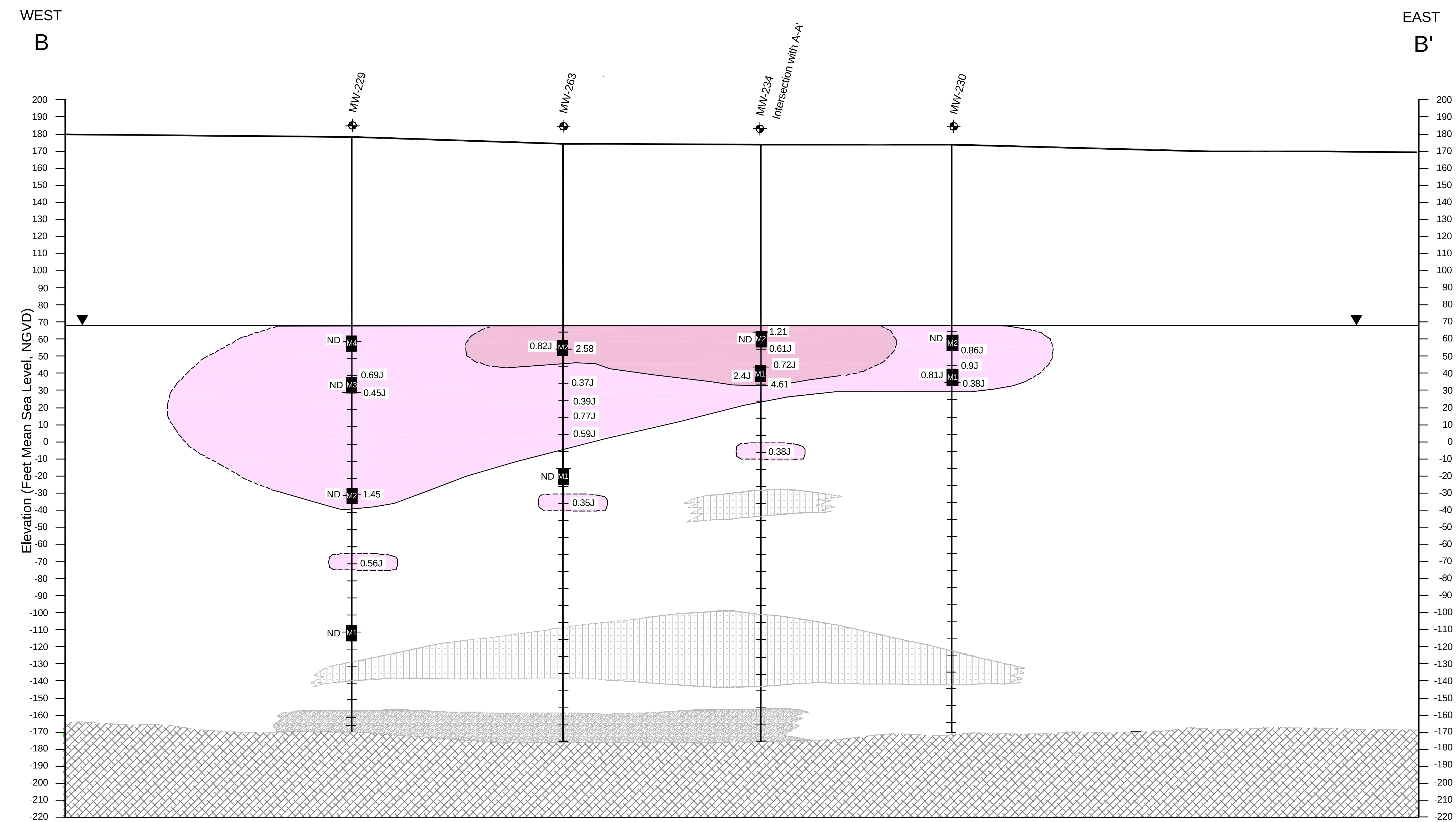
Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP j2_cross_section_aa_per_033005.dwg

Figure 2-1b



WEST
B
EAST
B'
MW-229
MW-263
MW-234
Intersection with A-A'
MW-230
Elevation (Feet Mean Sea Level, NGVD)
0.33
0.75J
1.2J
3.7J
2.2
5J
1.8J
6.2J
M1
M2
M3
M4
Legend
Monitoring Well
Water table
Well screen ID
Drilling Profile Interval Data (µg/L)
NS Not Sampled
DL Detection Limit
J Estimated Concentration
ND Nondetect
* Unvalidated Data
µg/L Micrograms per liter
Sand
Sand and Silt/Clay
Basal Gravel/Sand
Bedrock
Geologic Contact and Isoconcentration Contour (dashed where inferred)
Nondetect to 2 µg/L
2-10 µg/L
Greater than 10 µg/L
Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.
Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.
V: 60
H: 100
Scale in Feet
Impact Area Groundwater Study Program
J-2 North Cross-Section B-B'
RDX Distribution
Massachusetts Military Reservation
Cape Cod, Massachusetts
03/30/05 JP j2_cross_section_bb_rdx_033005.dwg
Figure 2-2a



Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.

Legend

- Monitoring Well
- Water table
- M1 Well screen ID

Drilling Profile Interval Data (μg/L)
2

NS	Not Sampled
DL	Detection Limit
J	Estimated Concentration
ND	Nondetect
*	Unvalidated Data
μg/L	Micrograms per liter

- Sand
- Sand and Silt/Clay
- Basal Gravel/Sand
- Bedrock
- Geologic Contact and Isoconcentration Contour (dashed where inferred)

- Nondetect to 1 μg/L
- 1-4 μg/L
- 4-18 μg/L
- Greater than 18 μg/L
- Greater than 100 μg/L

0
V: 60
H: 100
Scale in Feet

Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.

Impact Area Groundwater Study Program

J-2 North Cross-Section B-B'
Perchlorate Distribution
Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP j2_cross_section_bb_per_033005.dwg

Figure 2-2b

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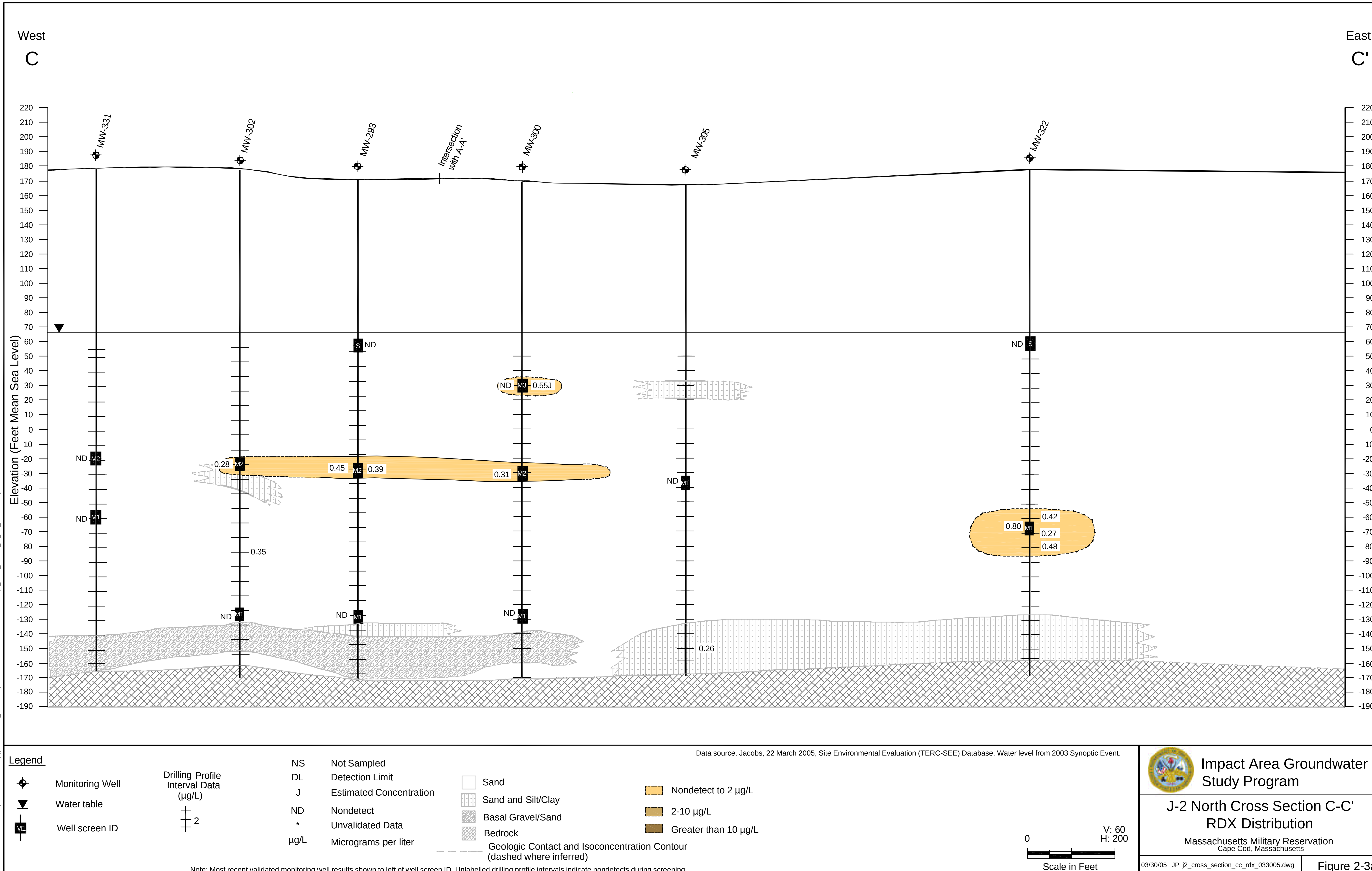

West
C
East
C'
Elevation (Feet Mean Sea Level)
MW-331
MW-302
MW-293
Intersection with A-A'
MW-300
MW-305
MW-322
ND
0.55J
0.28
0.45
0.39
0.31
0.35
0.26
0.80
0.42
0.27
0.48
Legend
Monitoring Well
Water table
Well screen ID
Drilling Profile Interval Data (µg/L)
NS Not Sampled
DL Detection Limit
J Estimated Concentration
ND Nondetect
* Unvalidated Data
µg/L Micrograms per liter
Sand
Sand and Silt/Clay
Basal Gravel/Sand
Bedrock
Geologic Contact and Isoconcentration Contour (dashed where inferred)
Nondetect to 2 µg/L
2-10 µg/L
Greater than 10 µg/L
Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.
Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.
V: 60
H: 200
Scale in Feet
Impact Area Groundwater Study Program
J-2 North Cross Section C-C'
RDX Distribution
Massachusetts Military Reservation
Cape Cod, Massachusetts
03/30/05 JP j2_cross_section_cc_rdx_033005.dwg
Figure 2-3a
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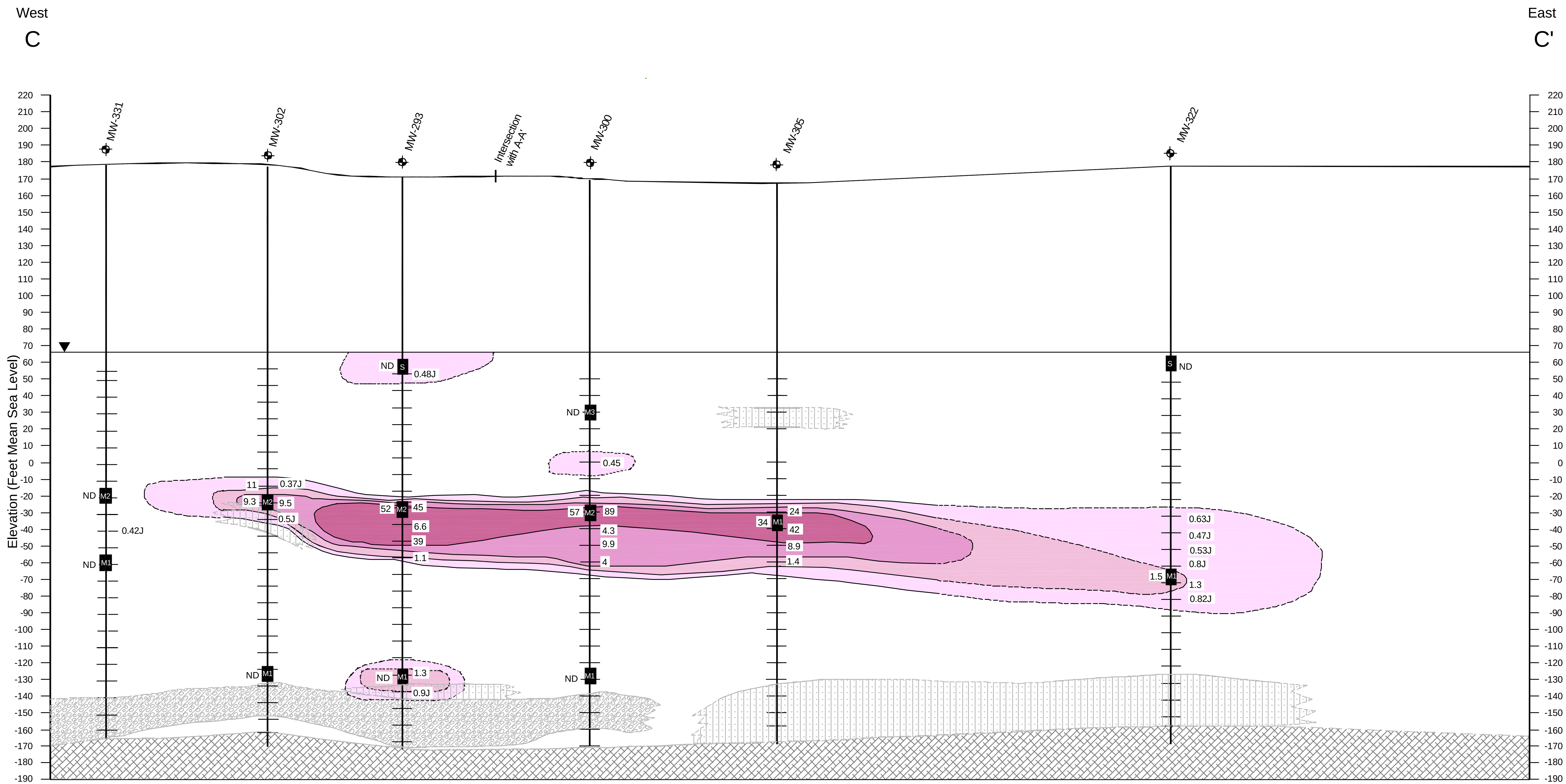

Legend

Monitoring Well

Water table

Well screen ID

Drilling Profile Interval Data (µg/L)

NS Not Sampled
DL Detection Limit
J Estimated Concentration
ND Nondetect
* Unvalidated Data
µg/L Micrograms per liter

Sand
Sand and Silt/Clay
Basal Gravel/Sand
Bedrock
Geologic Contact and Isoconcentration Contour (dashed where inferred)

Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.

Nondetect to 1 µg/L
1-4 µg/L
4-18 µg/L
Greater than 18 µg/L
Greater than 100 µg/L

Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.

V: 60
H: 200
0
Scale in Feet

Impact Area Groundwater Study Program

J-2 North Cross Section C-C' Perchlorate Distribution

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP j2_cross_section_cc_per_033005.dwg

Figure 2-3b

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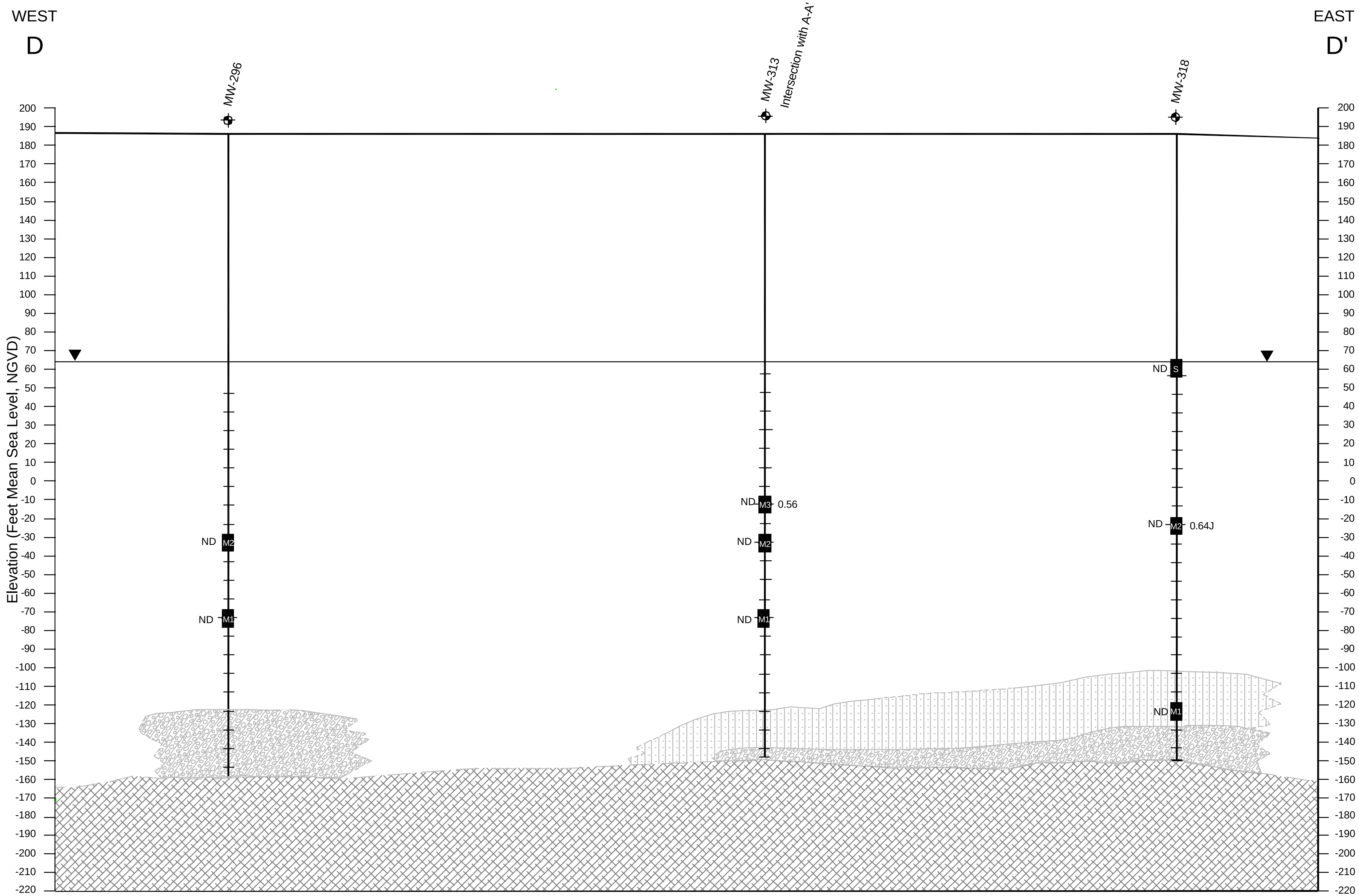

Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.

Legend

Monitoring Well

Water table

Well screen ID

Drilling Profile Interval Data (µg/L)

NS Not Sampled
DL Detection Limit
J Estimated Concentration
ND Nondetect
* Unvalidated Data
µg/L Micrograms per liter

Sand
Sand and Silt/Clay
Basal Gravel/Sand
Bedrock
Geologic Contact and Isoconcentration Contour (dashed where inferred)

Nondetect to 2 µg/L
2-10 µg/L
Greater than 10 µg/L

V: 60
H: 150
Scale in Feet

Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.

Impact Area Groundwater Study Program

J-2 North Cross Section D-D'
RDX Distribution
Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP j2_cross_section_dd_rdx_033005.dwg

Figure 2-4a

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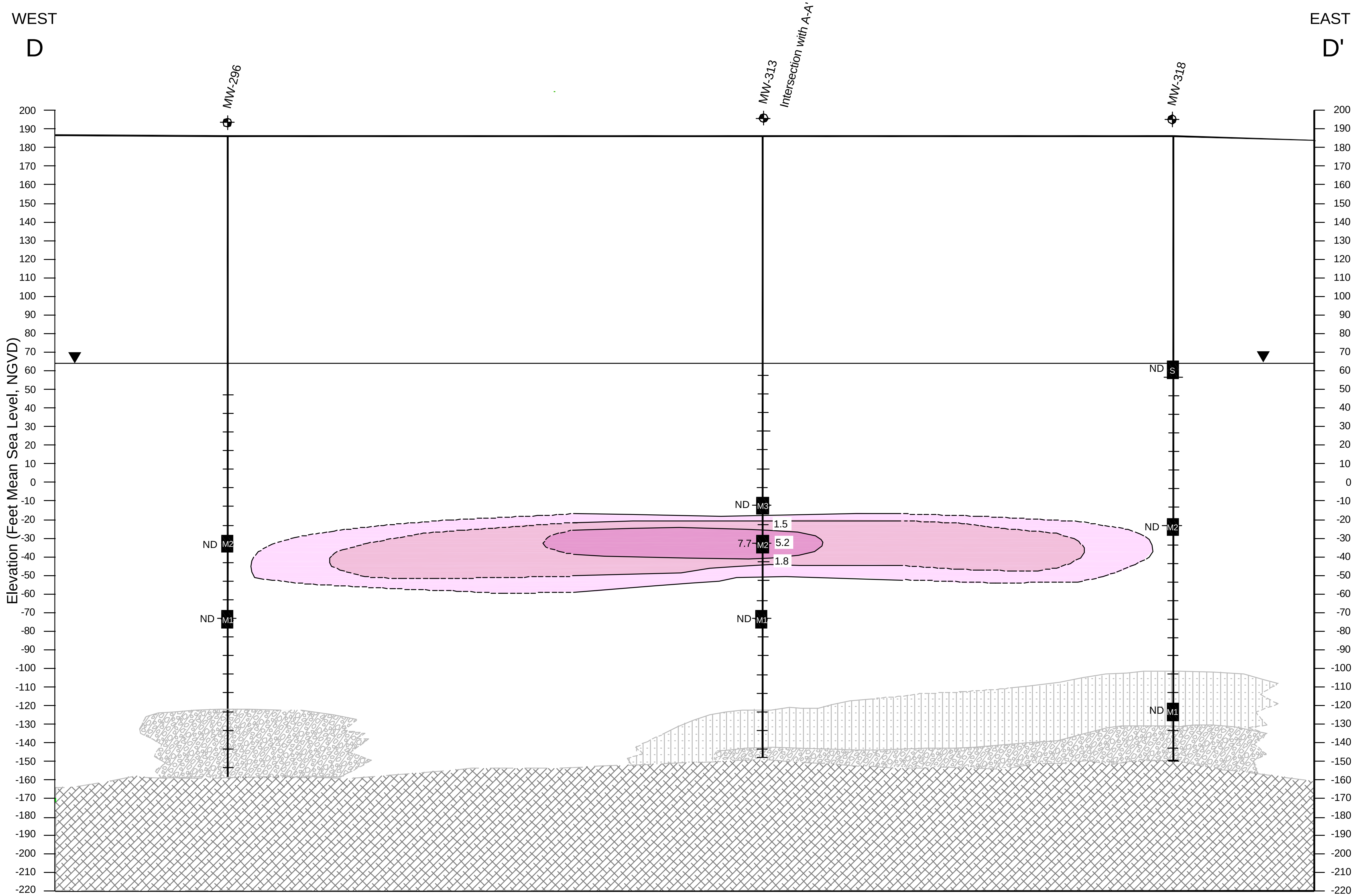

Data source: Jacobs, 22 March 2005, Site Environmental Evaluation (TERC-SEE) Database. Water level from 2003 Synoptic Event.

Legend

Monitoring Well

Water table

Well screen ID

Drilling Profile Interval Data (µg/L)

NS	Not Sampled
DL	Detection Limit
J	Estimated Concentration
ND	Nondetect
*	Unvalidated Data
µg/L	Micrograms per liter

Sand

Sand and Silt/Clay

Basal Gravel/Sand

Bedrock

Geologic Contact and Isoconcentration Contour (dashed where inferred)

Nondetect to 1 µg/L

1-4 µg/L

4-18 µg/L

Greater than 18 µg/L

Greater than 100 µg/L

V: 60
H: 150

0

Scale in Feet

Note: Most recent validated monitoring well results shown to left of well screen ID. Unlabelled drilling profile intervals indicate nondetects during screening.

Impact Area Groundwater Study Program

J-2 North Cross Section D-D' Perchlorate Distribution

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP j2_cross_section_dd_per_033005.dwg

Figure 2-4b

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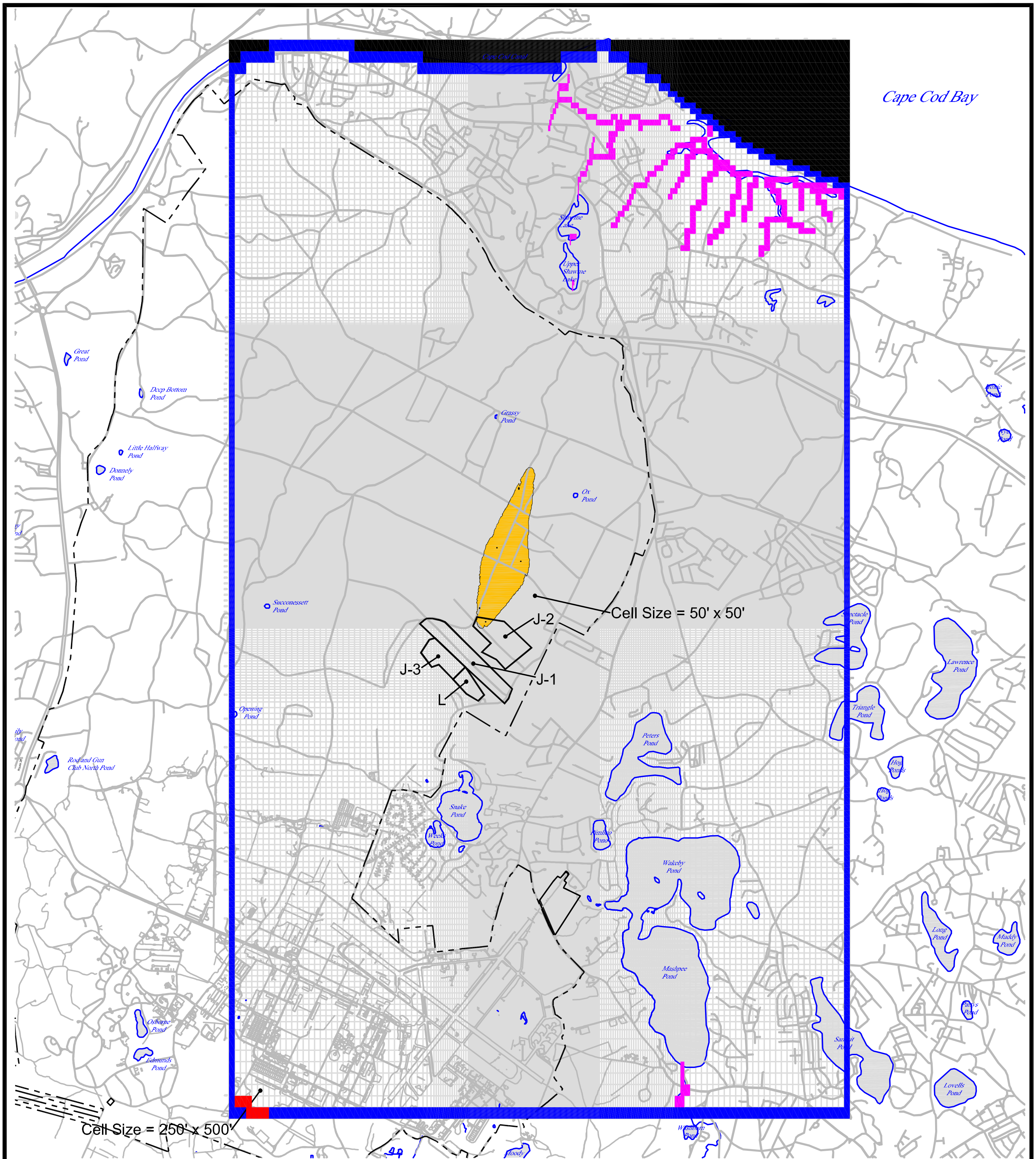


Legend

- Model Grid
- Constant Head Boundaries
- Wells in Model Layer 1
- Drain Cell
- No Flow Cell
- J-2 Plume

Notes

MMR Boundary

Minimum Cell Size = 50 x 50 feet

Maximum Cell Size = 250 x 500 feet

Total Number of Cells = 3,776,960

0 6000

Scale in Feet

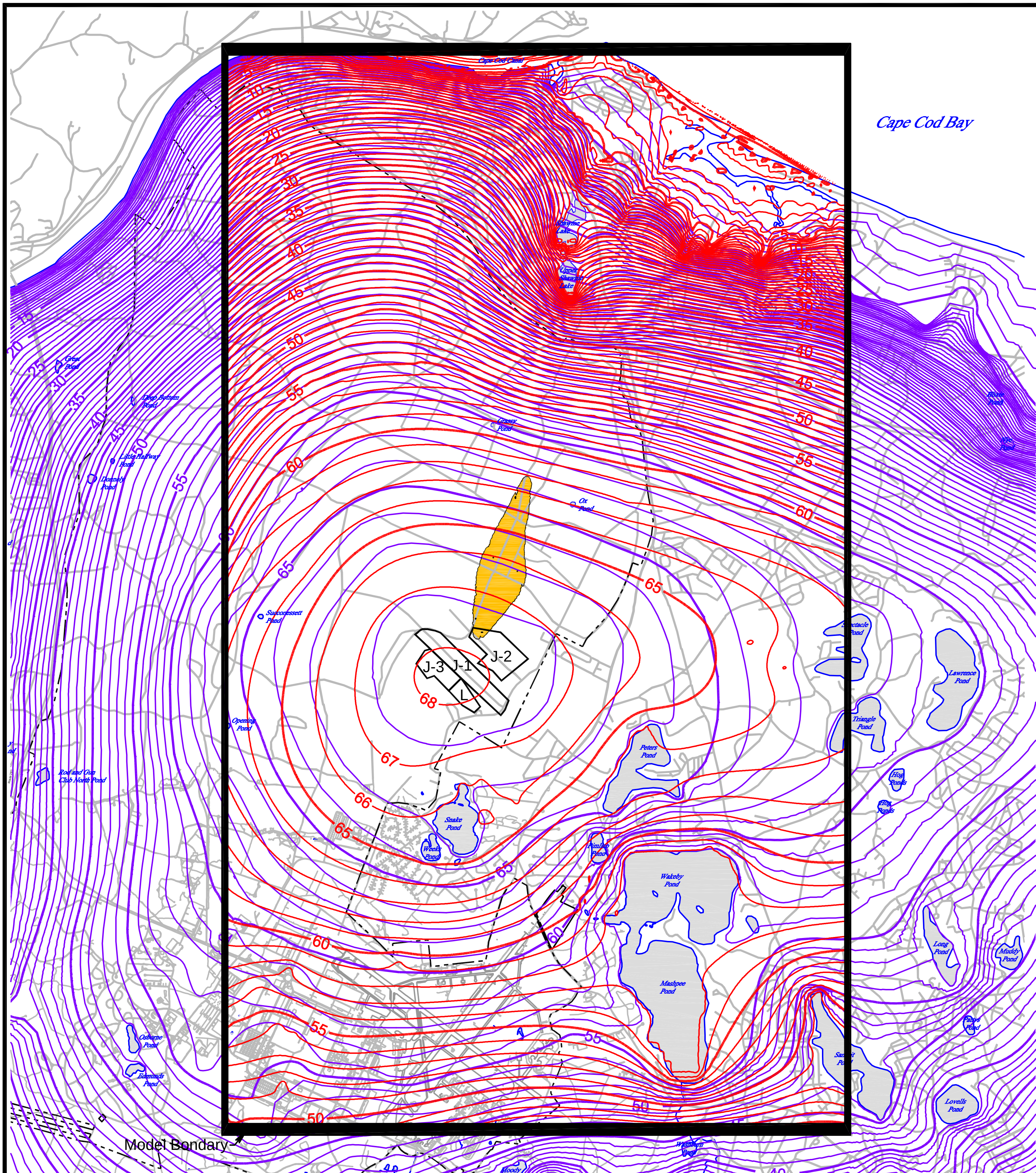
Impact Area Groundwater Study Program

J-2 Groundwater Model Domain and Grid

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP
Fig5-1 J-2 Model Domain2.dwg

Figure 5-1



Legend

68 — 2000 Synoptic Water Table Contour

65 — Model-Predicted Water Table Contours

J-2 Plume

0 6000

Scale in Feet

Impact Area Groundwater Study Program

2000 Synoptic Groundwater Elevations with Model-Predicted Values

Massachusetts Military Reservation

Cape Cod, Massachusetts

03/22/05 DF

Fig5-2 Syn GW.dwg

Figure 5-2

LEGEND

Forward ParticleTracks from the J-2 North Plume Source Area

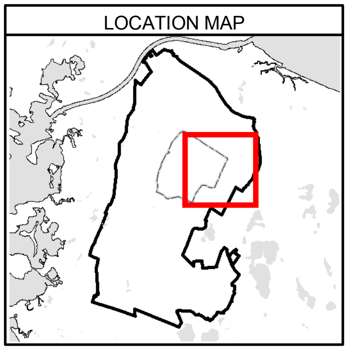
SE Ranges Plumes

MMR Boundary

CIA Central Impact Area Boundary

Range Boundary

NOTES:



0 1,000
Feet

NOTES & SOURCES
Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

Jacobs
Bourne, Massachusetts

Forward Particle Tracks from the
J-2 North Plume Source Area

FIGURE
5-3

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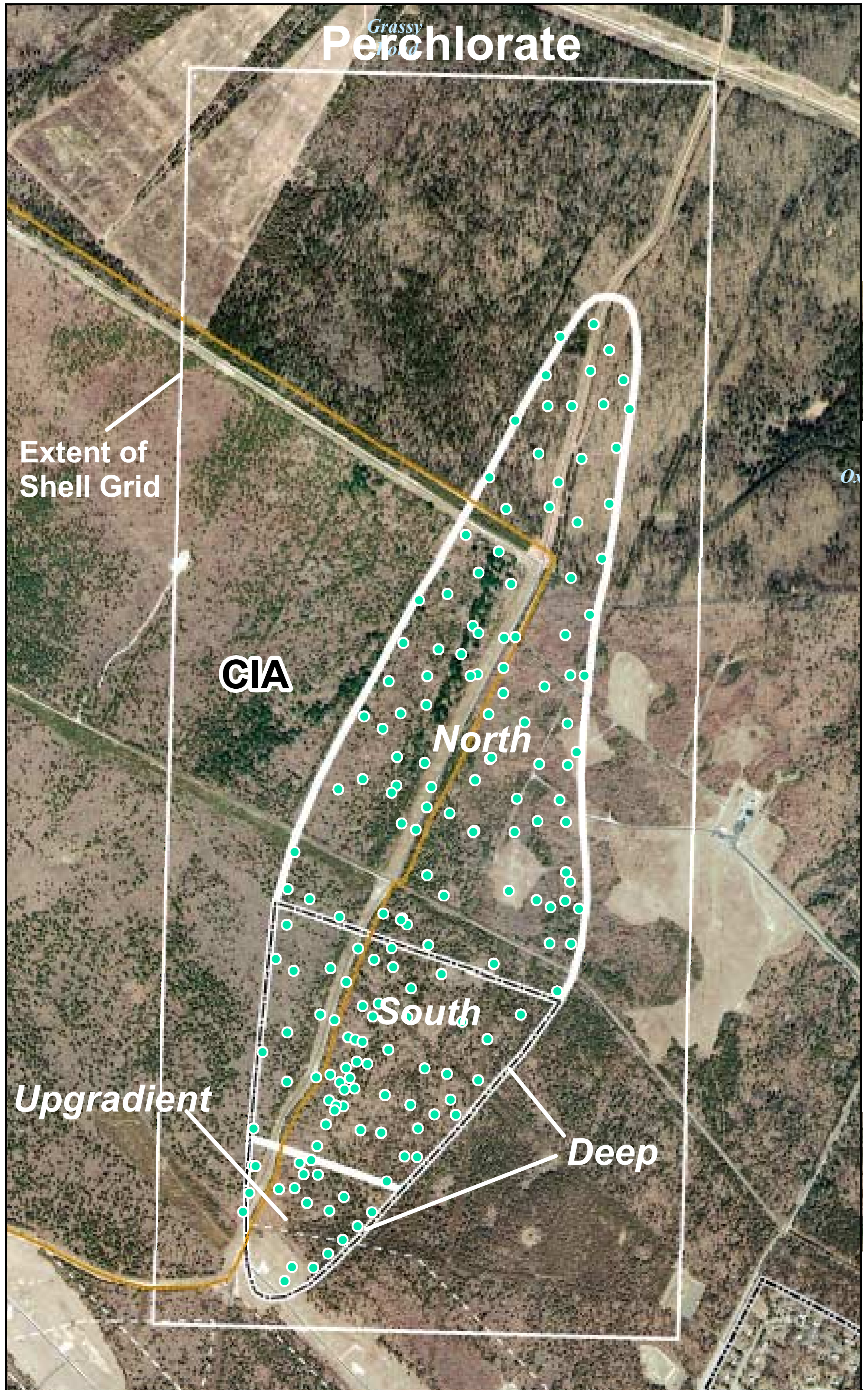
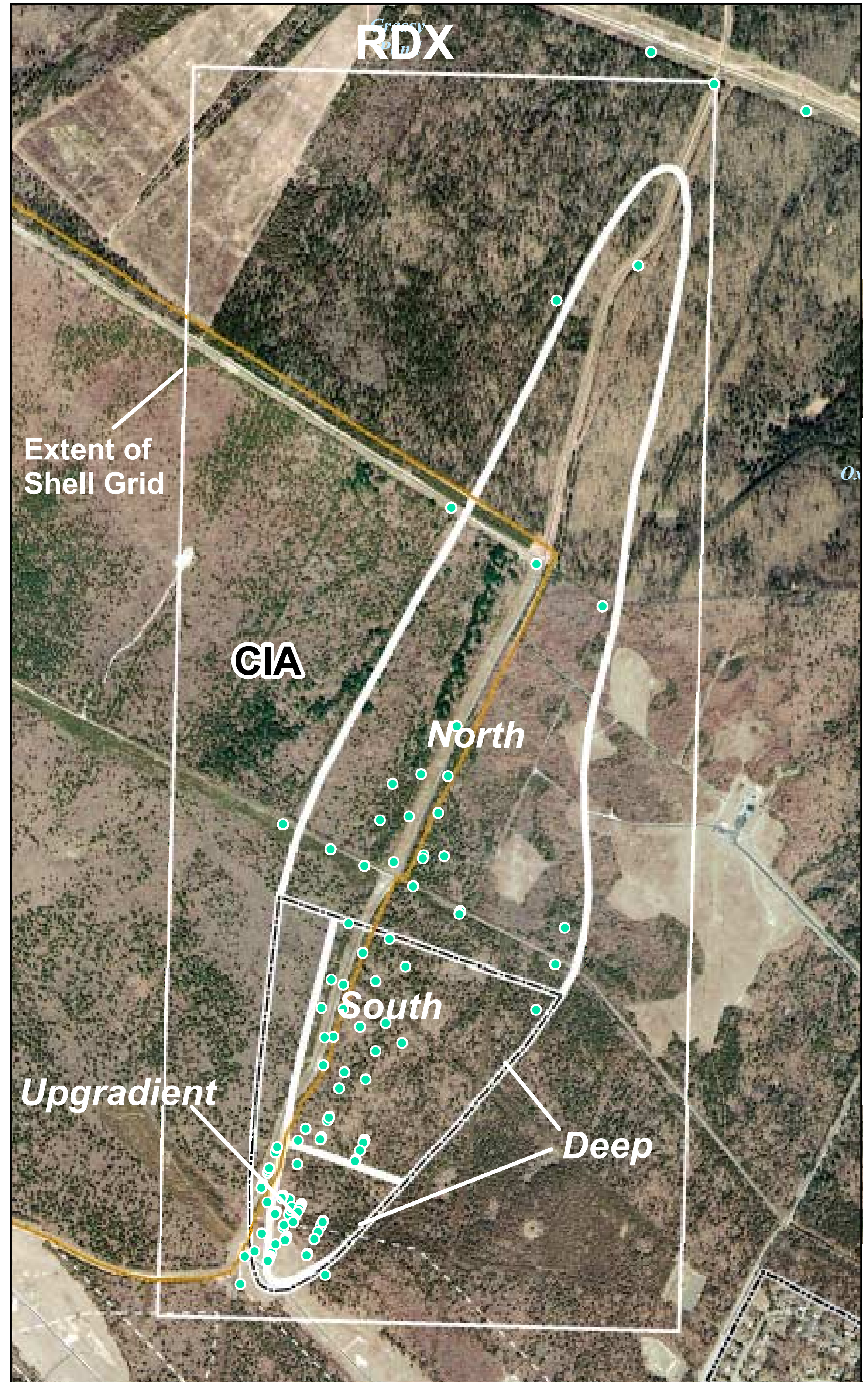
Run13_Source_Tracks2.mxd
March 30, 2005 NZehms Checked by JDefenderfer

Impact Area
Groundwater Study Program





Impact Area Groundwater Study Program

LEGEND

Location of control points, measured and/or migrated data.

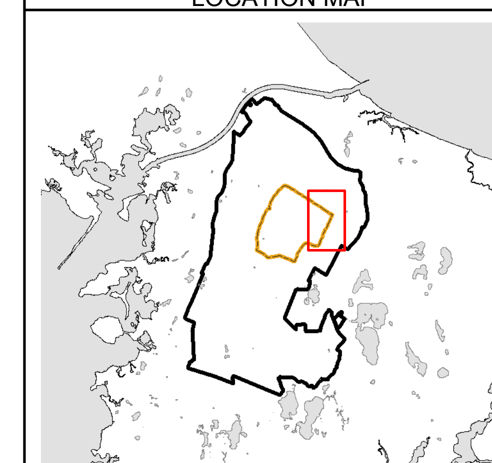
Deep Kriging Zone

CIA Central Impact Area Boundary

Range Boundary

Note: The white boundary inside the shell grid represents the conceptual outer limit for each analyte. The Deep kriging zone was used for grid points below the Upgradient and South kriging zones and below kriging grid layer 35 (layers 36-51; below about –105 ft msl).

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

J-2 North 2004 Plume Kriging Zones

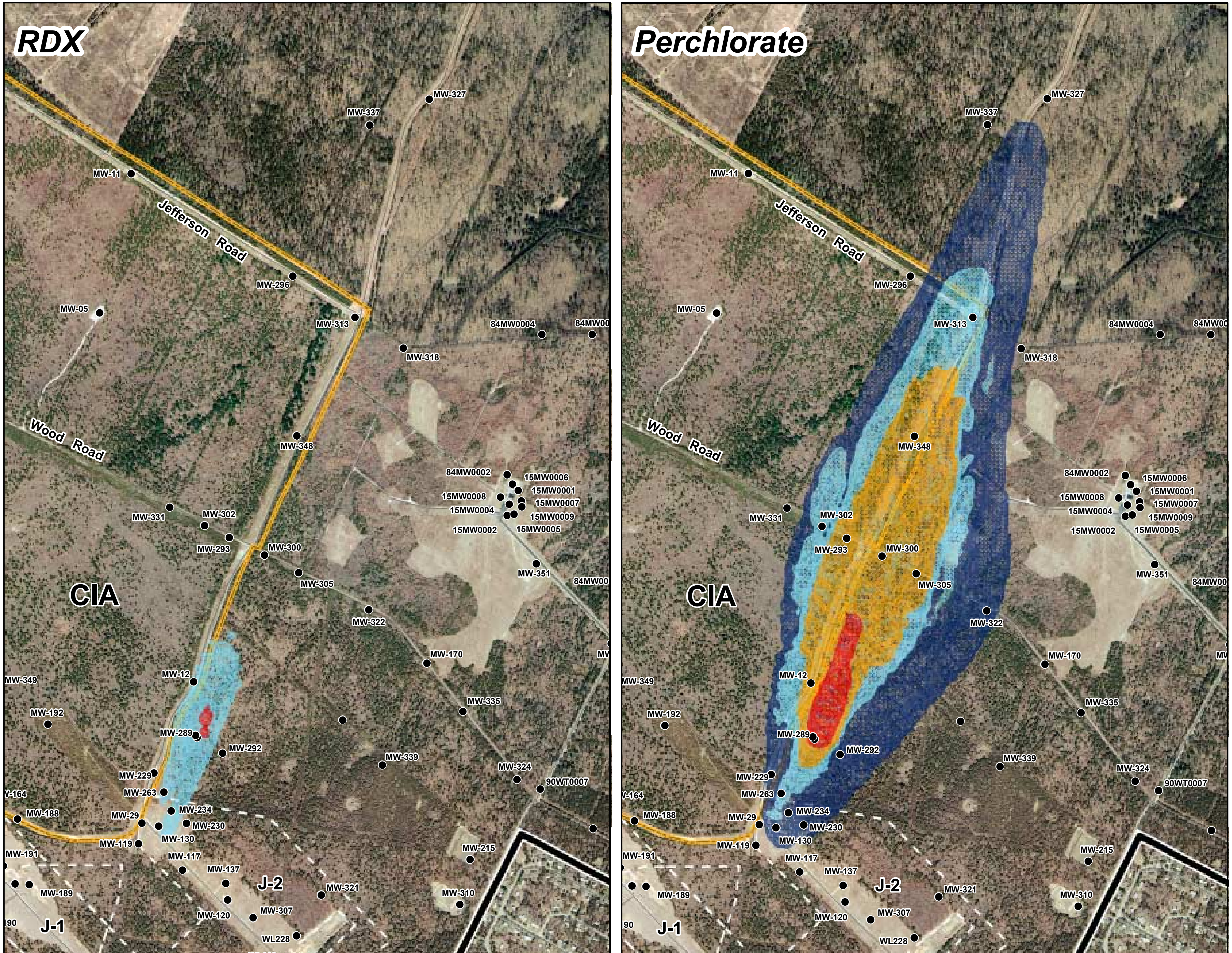
0 1,000
Feet

N

Jacobs
Bourne, Massachusetts

FIGURE 5-4

Y:\ia_terc\Projects\35AY53\01\20050330\
ArcGIS/J2_RANGE_krig_zones.mxd March 30, 2005
DWN BY: NZehms CHKD BY: LDemaree



Impact Area Groundwater Study Program

LEGEND

Perchlorate Concentration

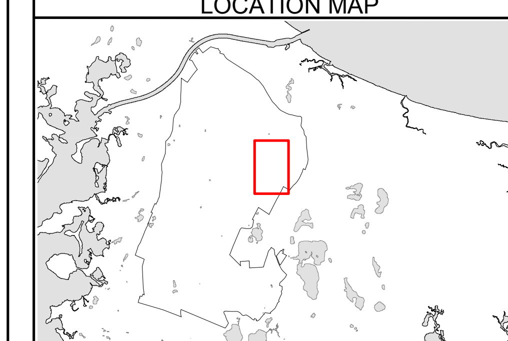
- 1 µg/L
- 18 µg/L
- 4 µg/L
- 100 µg/L

RDX Concentration

- 2 µg/L
- 8 µg/L
- Monitoring Well
- MMR Boundary
- CIA Central Impact Area Boundary
- Range Boundary

µg/L = micrograms per liter
RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

J-2 North 2004
Plume Shells

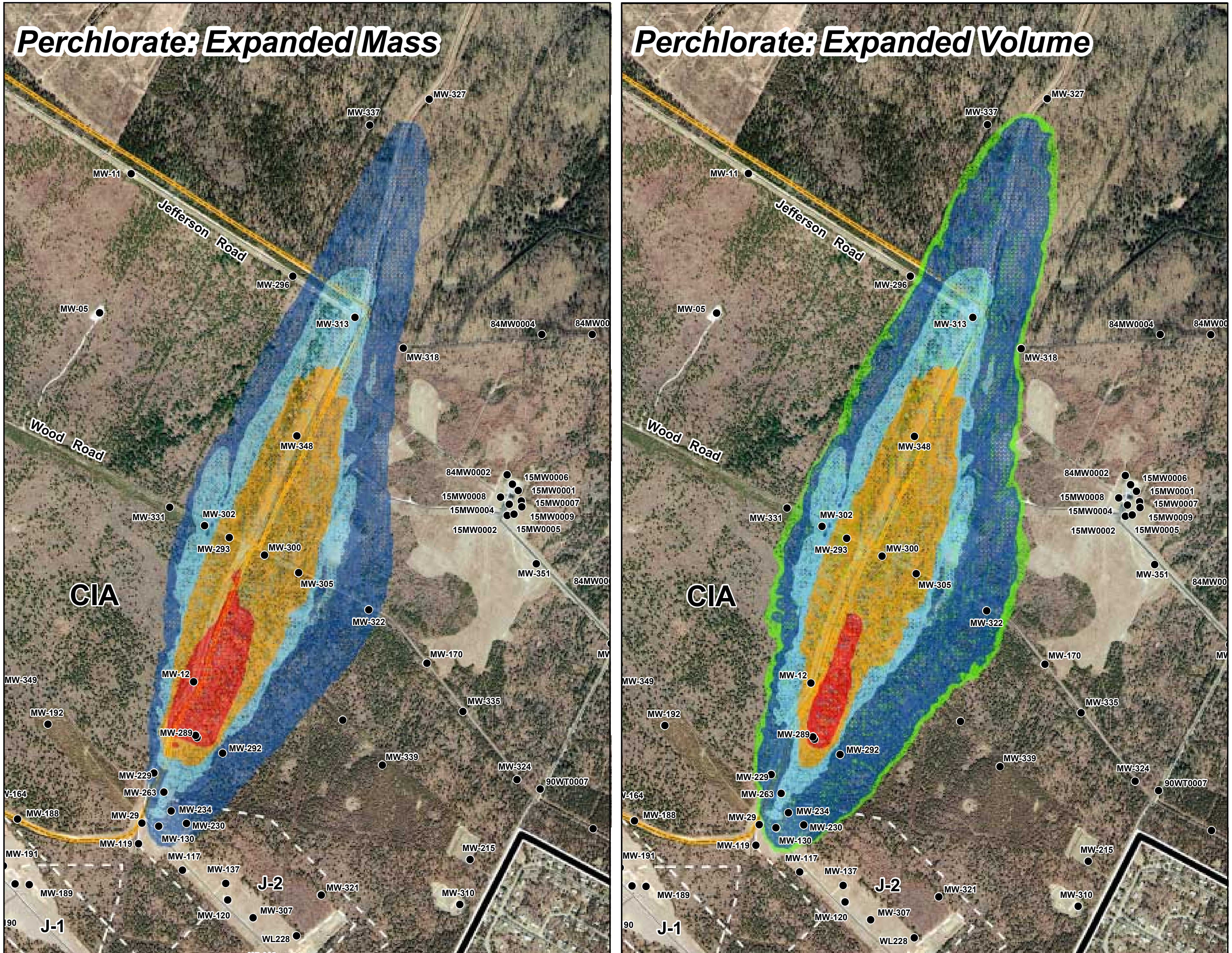
0 900 Feet

N

Jacobs
Bourne, Massachusetts

FIGURE
5-5

Y:\IA_TERC\Projects\35AY53\01\20050330\ArcGIS
J2_rdx_per_plumeshell2.mxd
March 30, 2005 NZehms Checked by LDemaree



Impact Area Groundwater Study Program

LEGEND

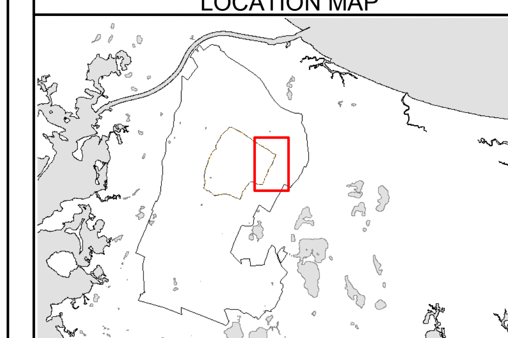
Perchlorate Concentration

0.35 µg/L
1 µg/L
4 µg/L
18 µg/L
100 µg/L

Monitoring Well
MMR Boundary
CIA Central Impact Area Boundary
Range Boundary

µg/L = micrograms per liter

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

J-2 North 2004 Sensitivity Plume Shells

0 900 Feet

N

Jacobs
Bourne, Massachusetts

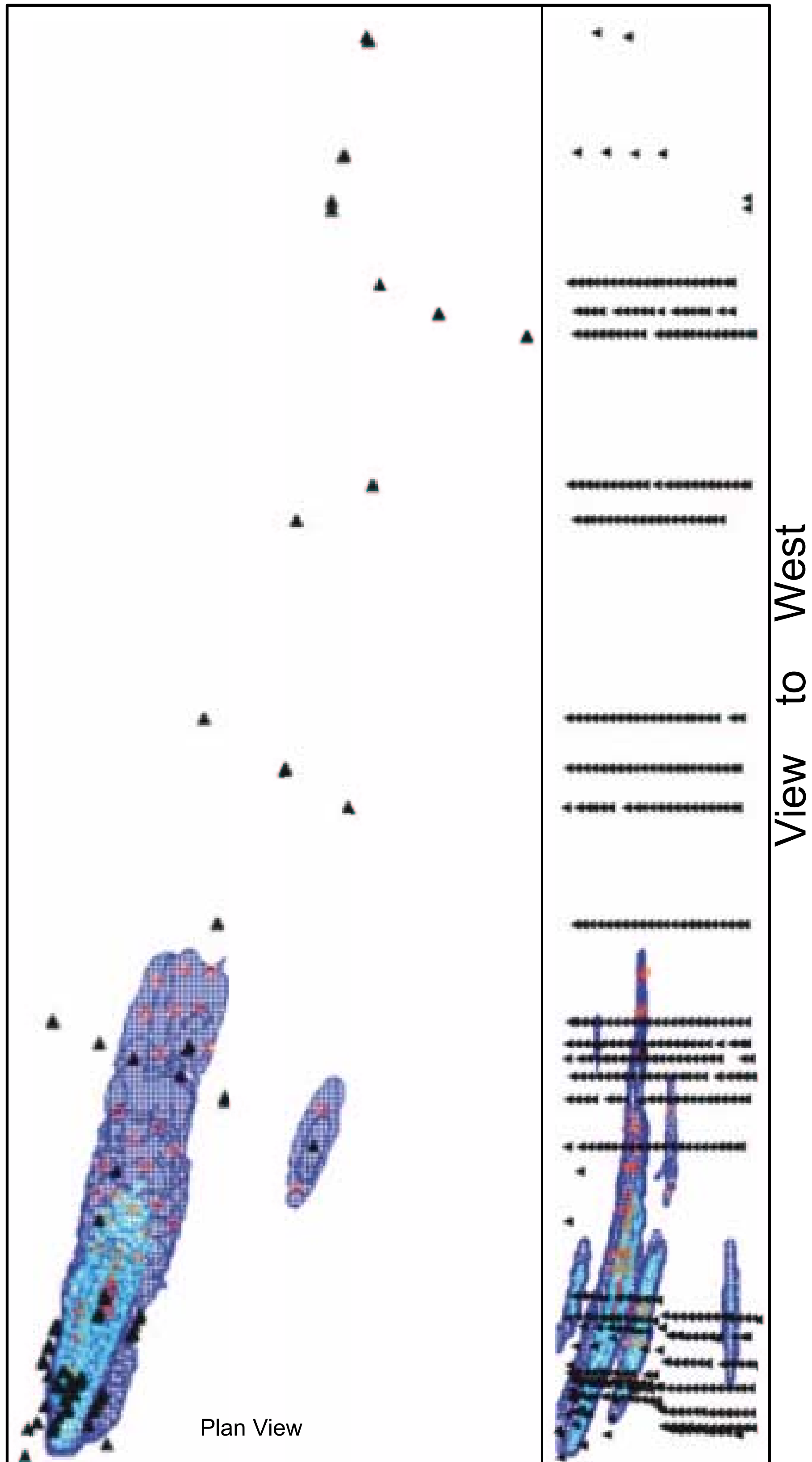
FIGURE 5-6

Y:\IA_TERC\Projects\35AY53\01\20050330\ArcGIS
DL_J2_rdx_per_plumeshell2.mxd
March 30, 2005 NZehms Checked by LDemaree

All Data (All measured data and control points used in kriging)

Mass = 0.75 kg (above 0.25 µg/L cut-off)

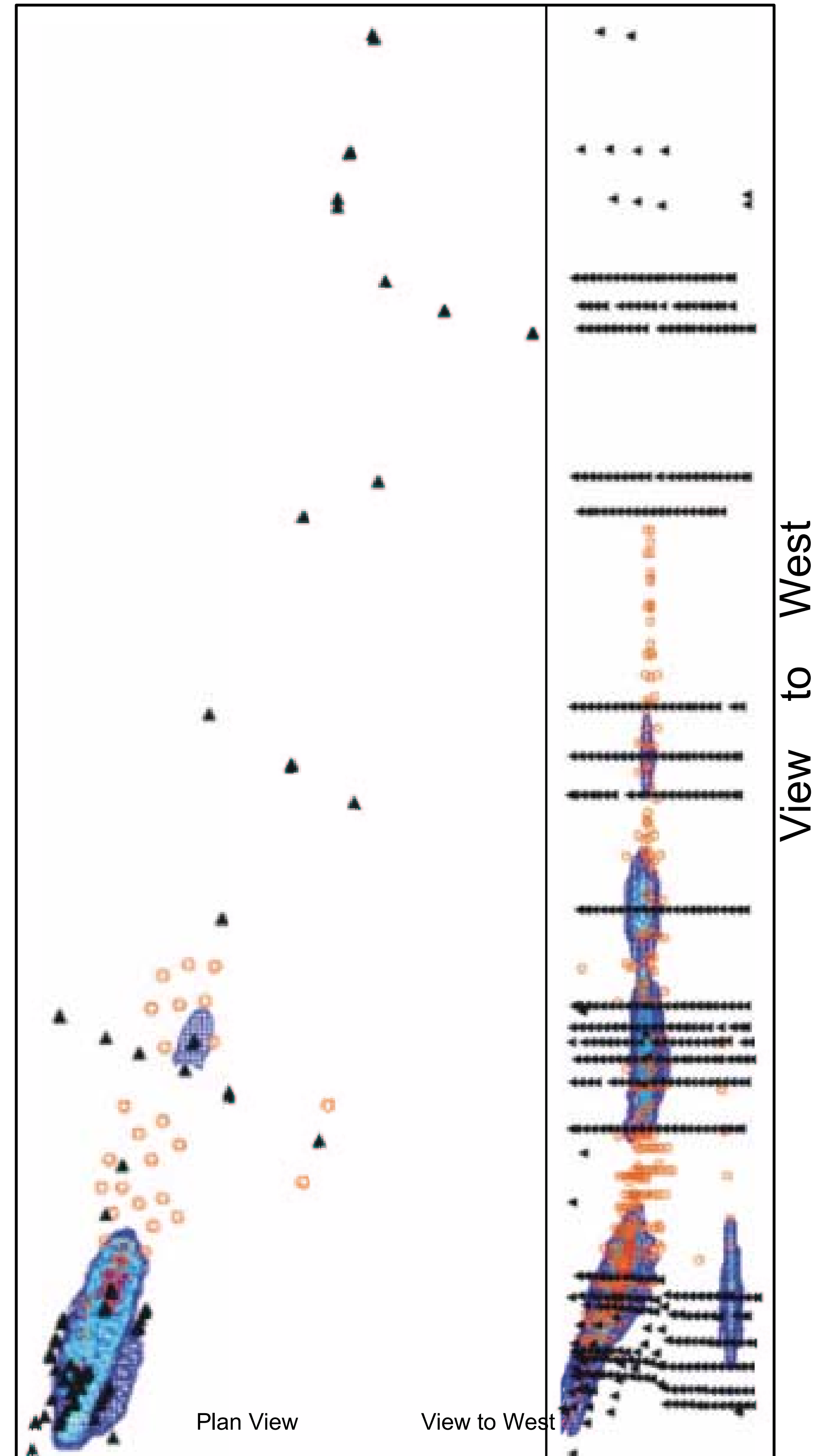
Volume = 17.3 X 10^6 ft^3 (above 0.25 µg/L cut-off)



Measured Data Only (No control points used in kriging)

Mass = 0.37 kg (above 0.25 µg/L cut-off)

Volume = 6.94 X 10^6 ft^3 (above 0.25 µg/L cut-off)



Impact Area Groundwater Study Program

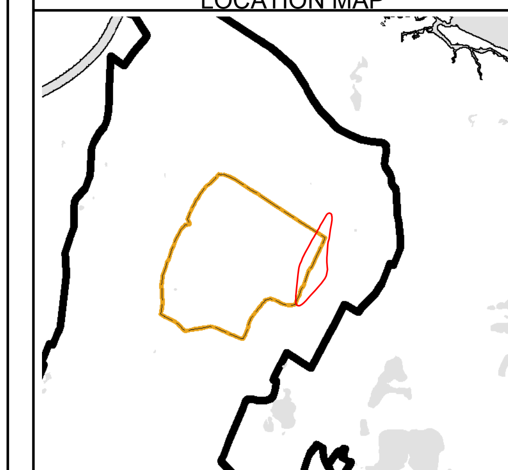
LEGEND

RDX Concentration

- 0.25 µg/L
- 2 µg/L
- 8 µg/L
- Measured and Migrated Data
- Control Points

ft3 = cubic feet
kg = kilograms
µg/L = micrograms per liter
RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

Data Density Analysis for the J-2 North RDX 2004 Plume Shell

0 1,000 Feet

N

Jacobs
Bourne, Massachusetts

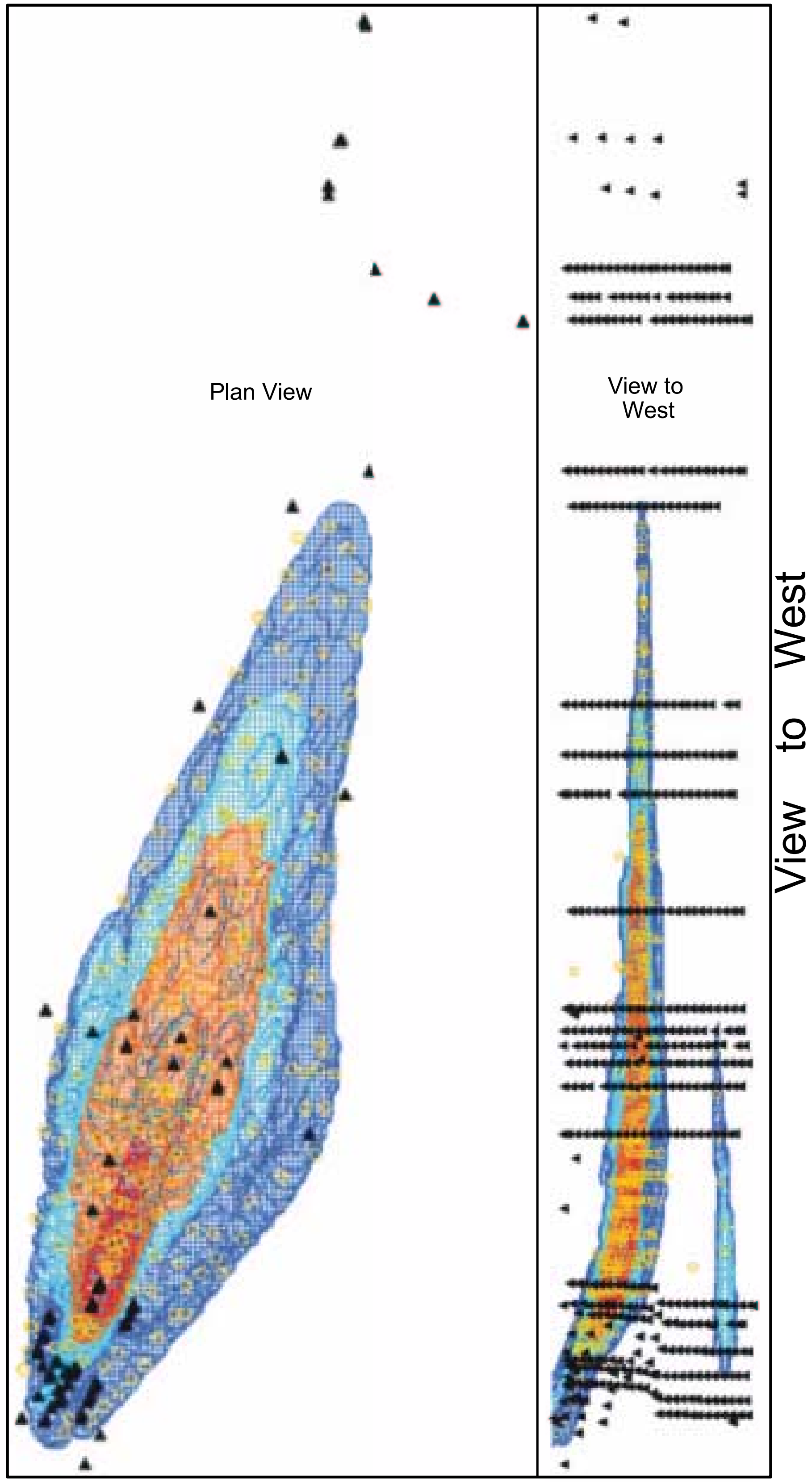
Y:\Ia_terc\Projects\35AY53\01\20050330\
ArcGIS/RDX_Data_Density2.mxd March 30, 2005
DWN BY: NZehms CHKD BY: LDemaree

FIGURE 5-7

All Data (All measured data and control points used in kriging)

Mass = 29.0 kg (above 1.00 µg/L cut-off)

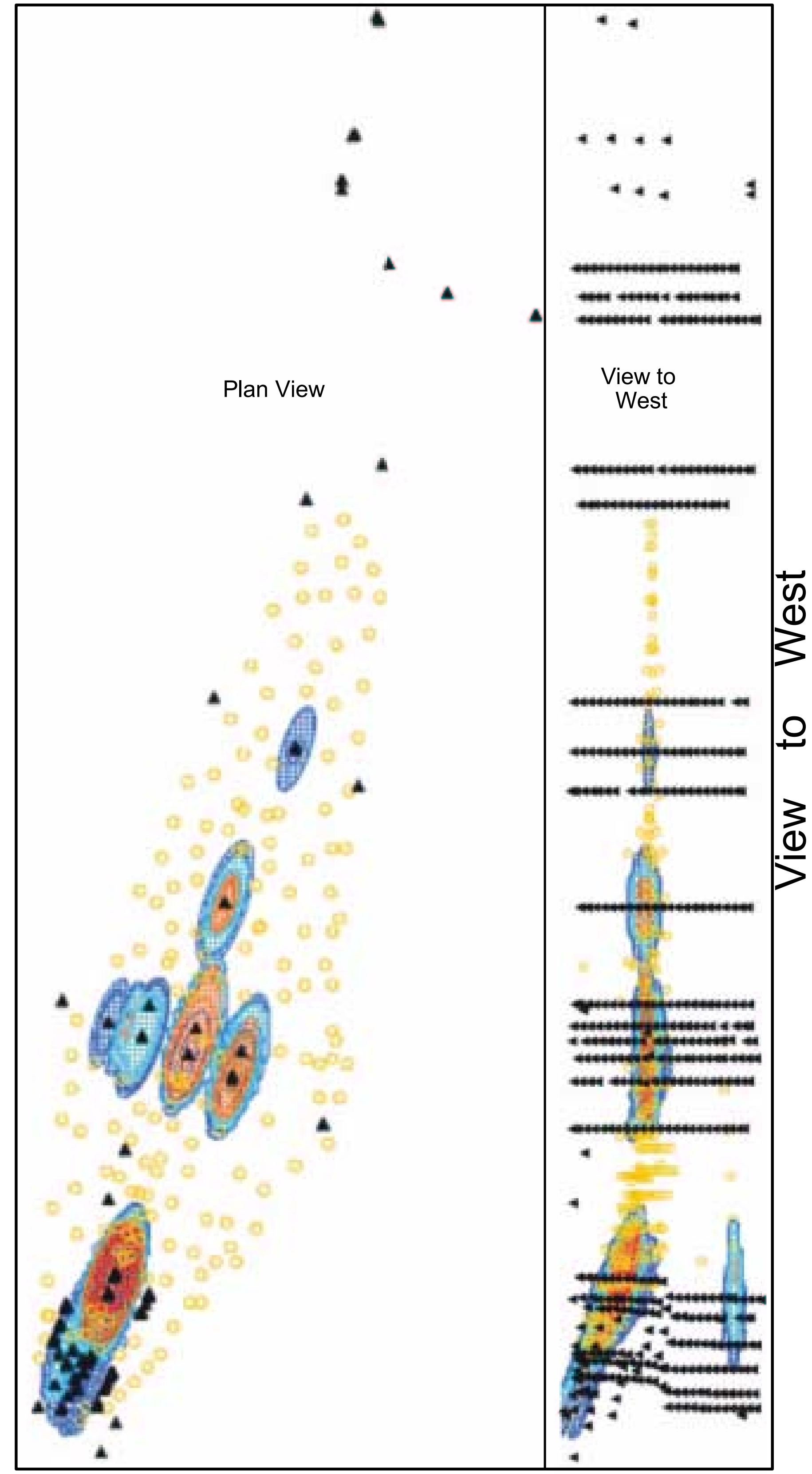
Volume = 68.3 X 10^6 ft^3 (above 1.00 µg/L cut-off)



Measured Data Only (No control points used in kriging)

Mass = 7.78 kg (above 1.00 µg/L cut-off)

Volume = 13.1 X 10^6 ft^3 (above 1.00 µg/L cut-off)



Impact Area Groundwater Study Program

LEGEND

Perchlorate Concentration

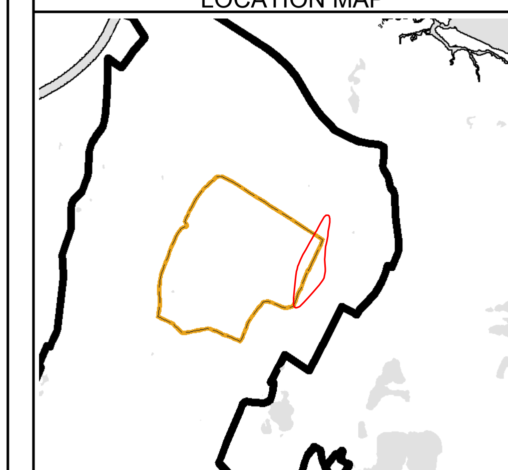
1.00 µg/L
18 µg/L
4 µg/L
100 µg/L

▲ Measured and Migrated Data

○ Control Points

ft3 = cubic feet
kg = kilograms
µg/L = micrograms per liter

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

Data Density Analysis for the J-2 North Perchlorate 2004 Plume Shell

0 1,000
Feet

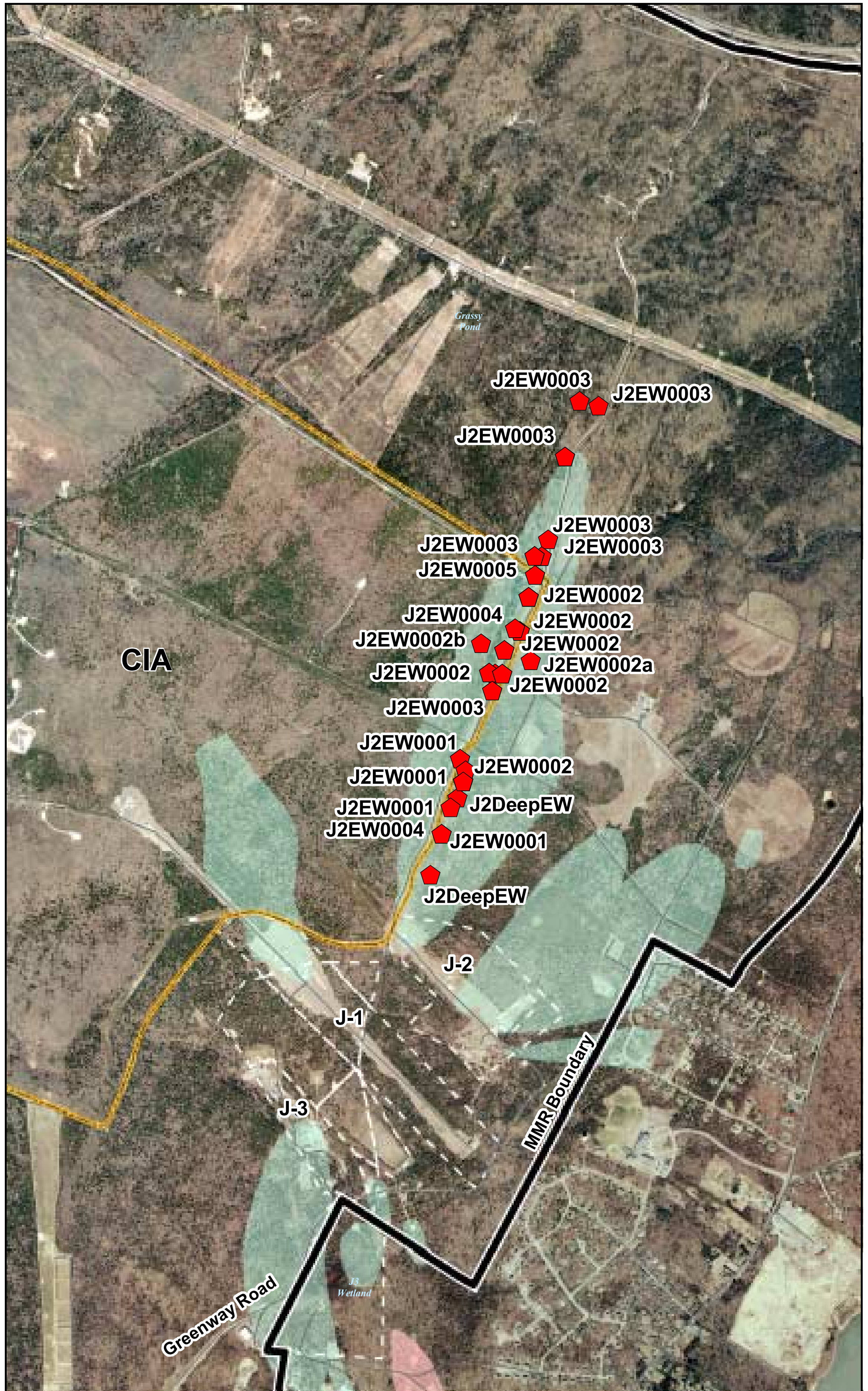
N

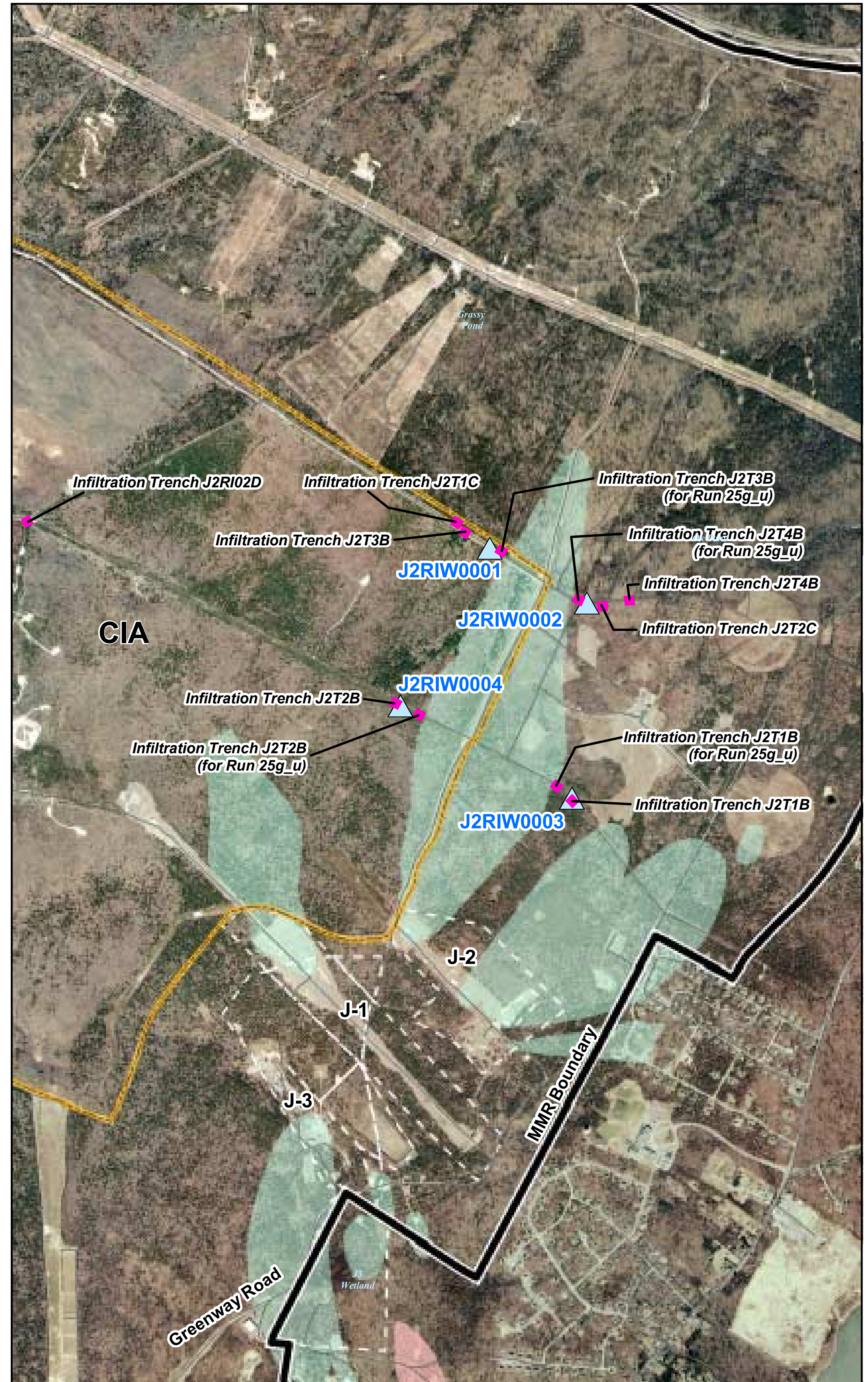
Jacobs
Bourne, Massachusetts

Y:\Ia_terc\Projects\35AY53\01\20050330\
ArcGIS/Per_Data_Density2.mxd March 30, 2005
DWN BY: NZehms CHKD BY: LDemaree

FIGURE
5-8

Impact Area
Groundwater Study Program

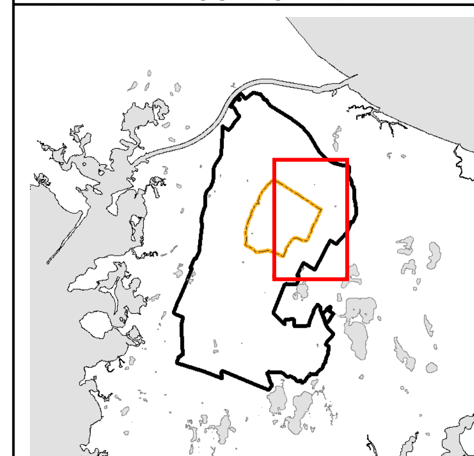




LEGEND

- Simulated J-2 Extraction Well
- Simulated J-2 Re-Injection Well
- Simulated J-2 Infiltration Trench
- SE Ranges Plumes
- MMR Boundary
- CIA Central Impact Area Boundary
- Range Boundary

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

Various Extraction Well, Re-Injection Well, and Infiltration Trench Locations Simulated for J-2 RRA Wellfield Design

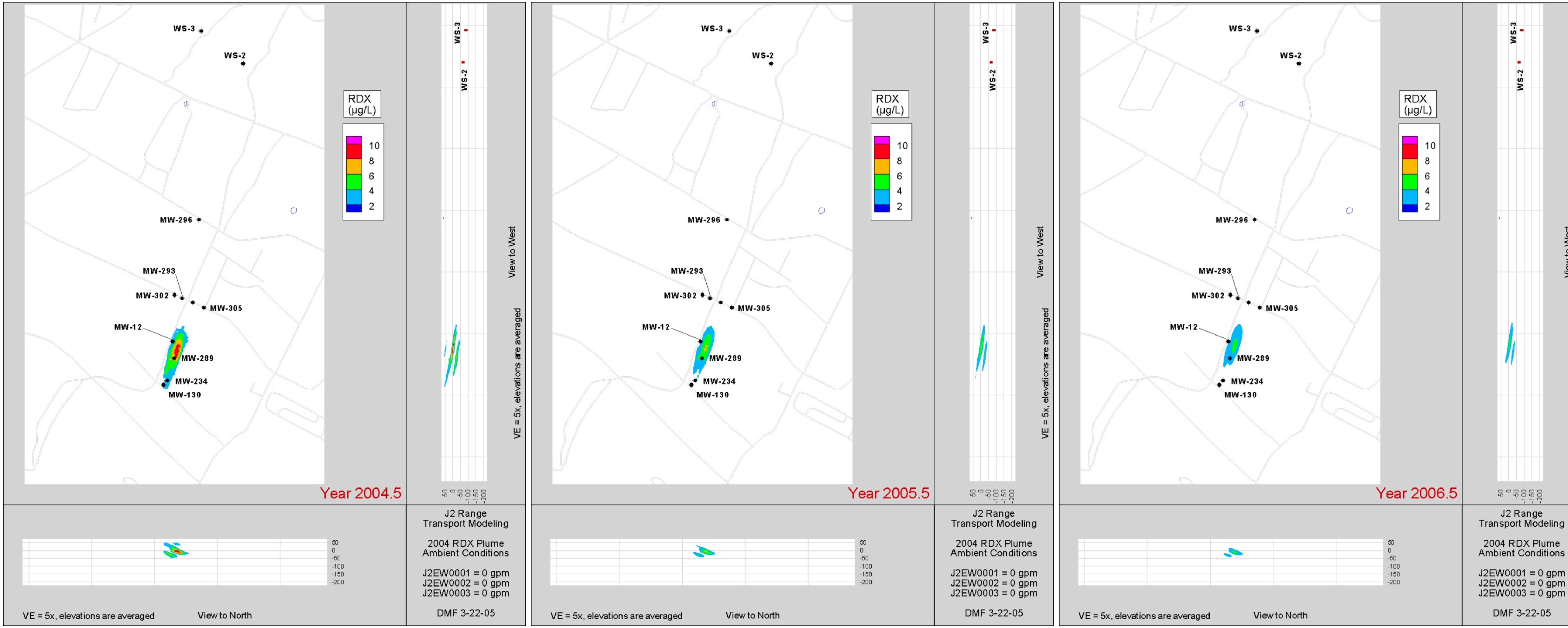
0 1,000 2,000
Feet

N

Jacobs
Bourne, Massachusetts

Y:\Ia_terc\Projects\35AY53\01\20050330\
ArcGIS\J2RRA_Extraction_Reinjection_Locs2.mxd March 30, 2005
DWN BY: NZehms CHKD BY: LDemaree

FIGURE
5-9



Legend

Extraction Well

Reinjection Well

Notes

Health Advisory = 2 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800

Scale in Feet

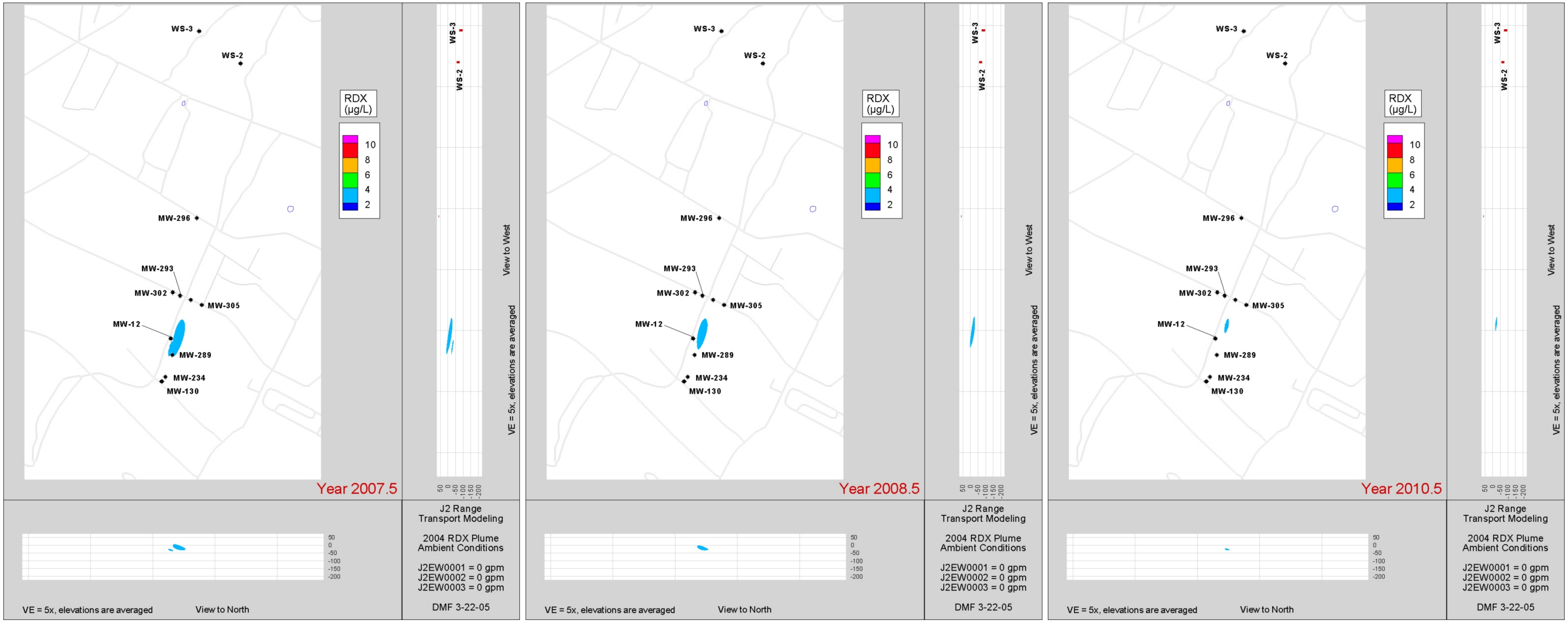
JACOBS

Model-Predicted RDX Concentrations
MMR Remedial Systems
Ambient Conditions

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-10a RDX_Avg_Op.cdr

Figure 5-10a



Legend

- Extraction Well
- Reinjection Well

Notes

Health Advisory = 2 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800
Scale in Feet

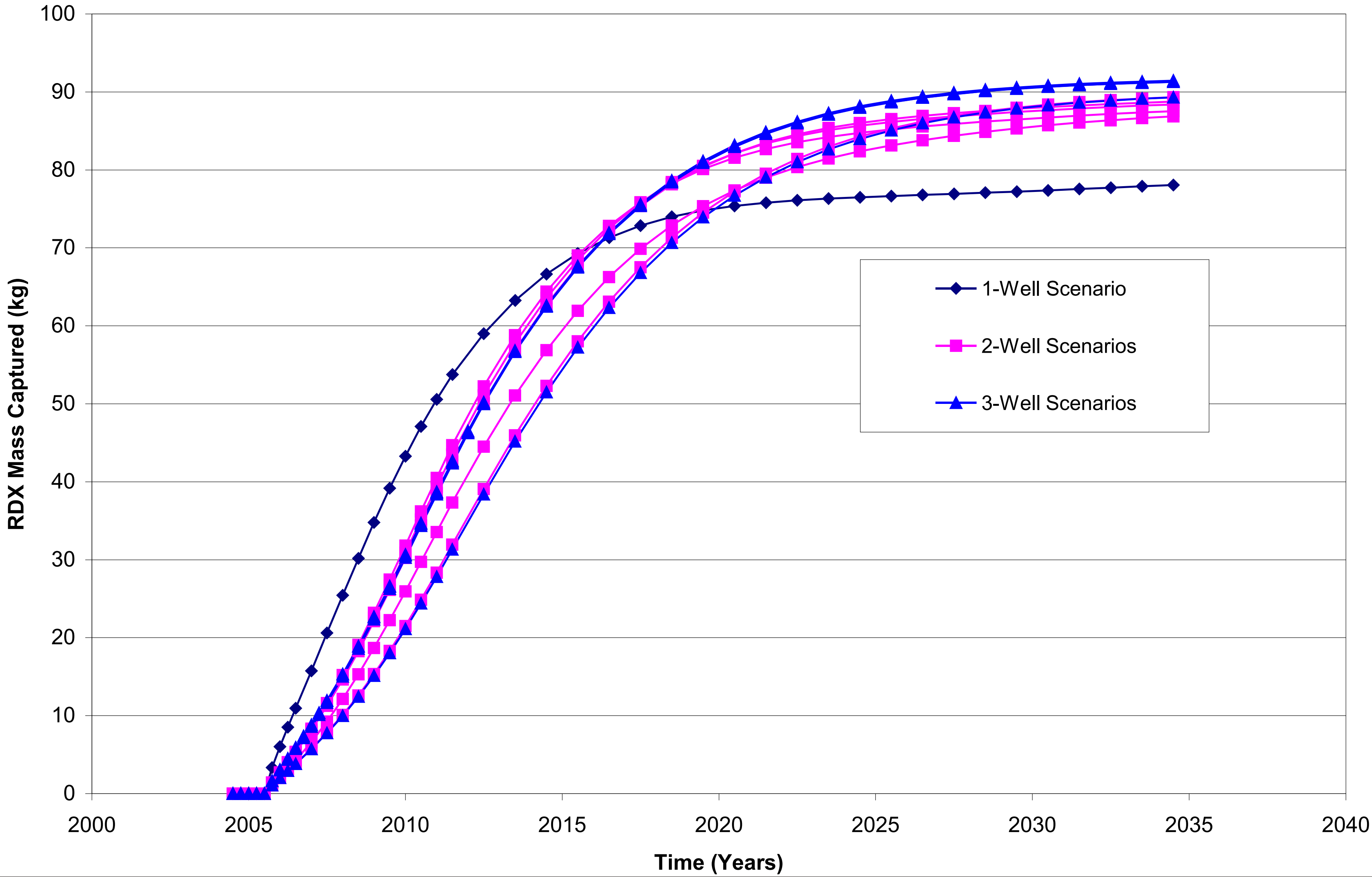
JACOBS

Model-Predicted RDX Concentrations
MMR Remedial Systems
Ambient Conditions

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-10b RDX_Avg_Op.cdr

Figure 5-10b



Note:
The flow rate for the one-well scenario was 90 gpm, flow rates for all two-well scenarios depicted were 175 gpm and flow rates for all three-well scenarios depicted were 375 gpm.

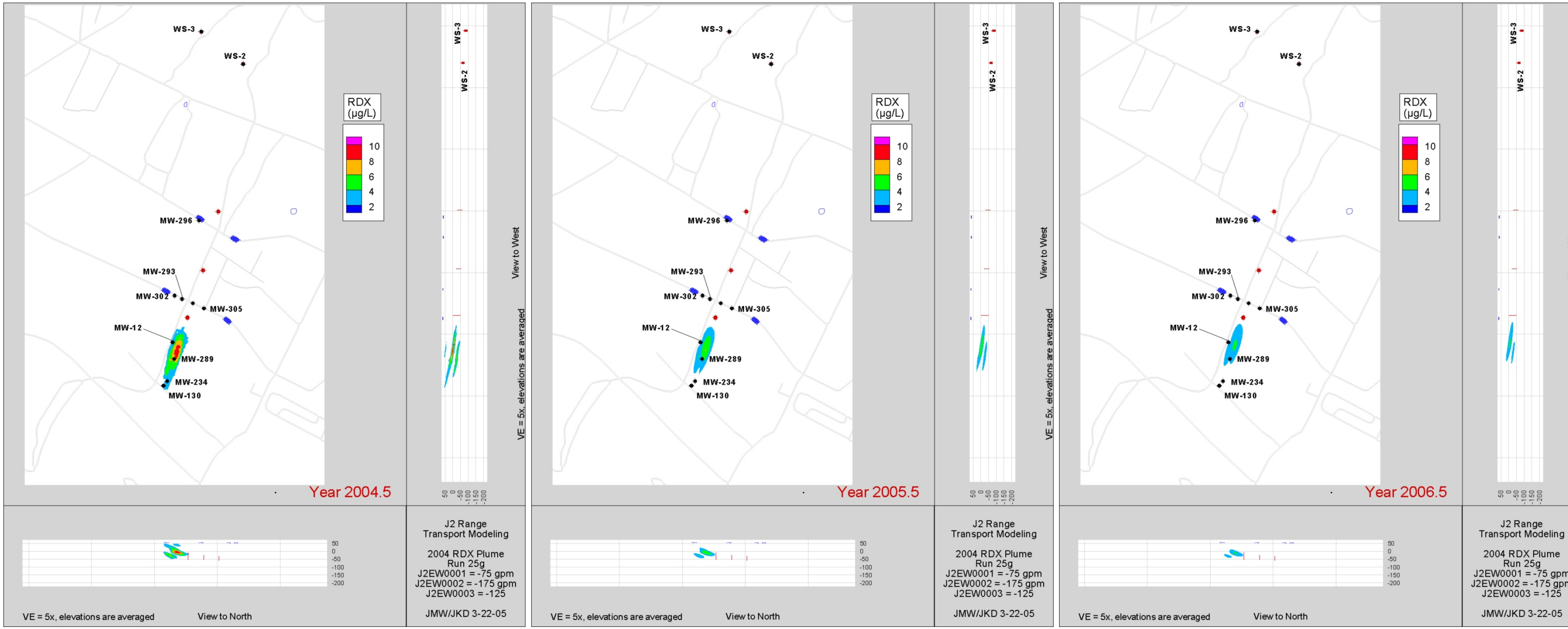
Impact Area Groundwater Study Program

J-2 North RDX Mass Capture for 1, 2 and 3-well Scenarios

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/10/05 DMF
Fig5-11 RDX_Mass_Capt.cdr

Figure 5-11



Legend

- Extraction Well
- Reinjection Well

Notes

Health Advisory = 2 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800

Scale in Feet

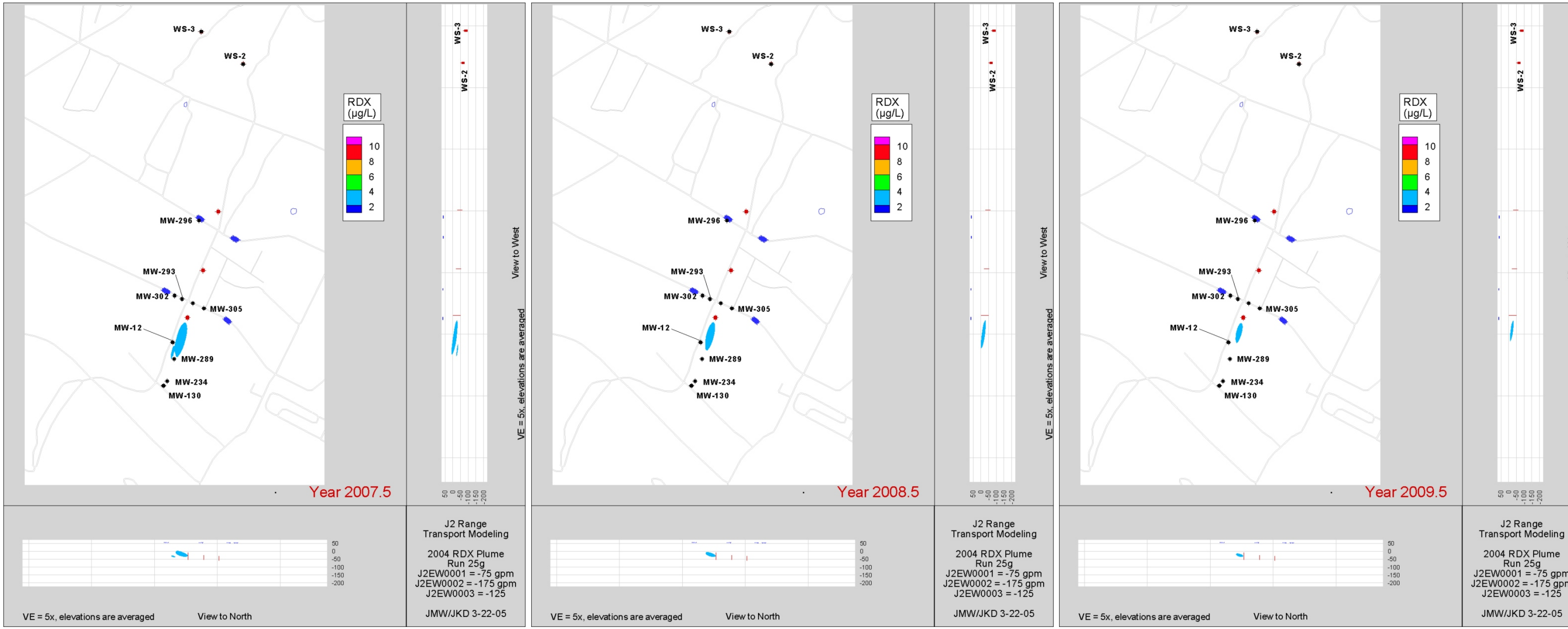
JACOBS

Model-Predicted RDX Concentrations
Scenario 25g_u

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-12a RDX_Run25g_u.cdr

Figure 5-12a



Legend

- Extraction Well
- Reinjection Well

Notes

Health Advisory = 2 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800
Scale in Feet

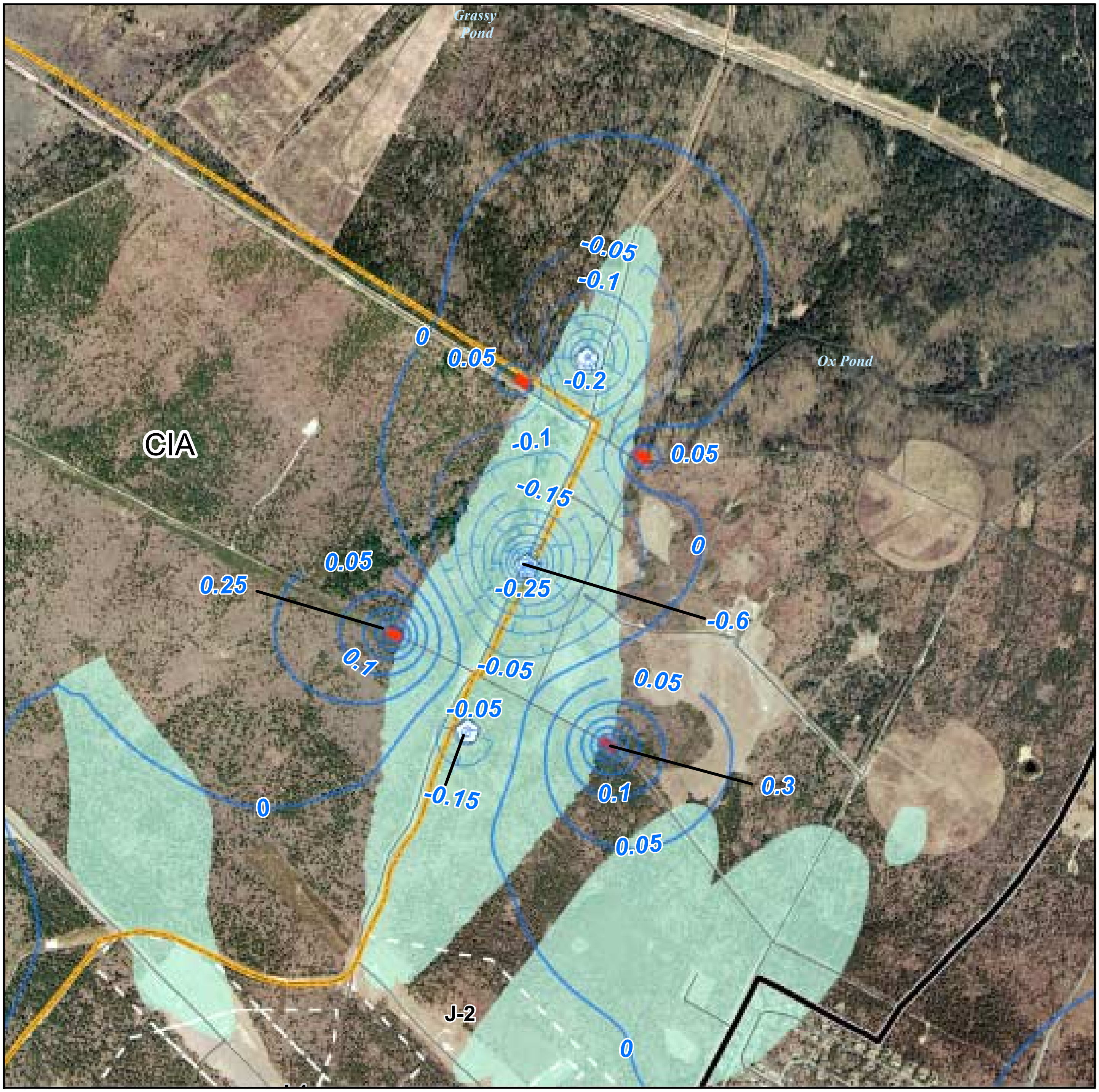
JACOBS

Model-Predicted RDX Concentrations
Scenario 25g_u

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-12b RDX_Run25g_u.cdr

Figure 5-12b



LEGEND

Proposed J-2 Extraction Well

Proposed J-2 Re-Injection Trench

Predicted Mounding for Model Run 25g_u

Predicted Drawdown for Model Run 25g_u

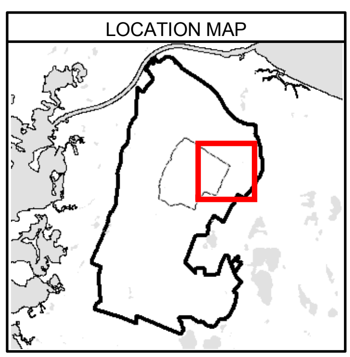
SE Ranges Plumes

CIA Central Impact Area Boundary

MMR Boundary

Range Boundary

NOTES:



0 1,000
Feet

NOTES & SOURCES
Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

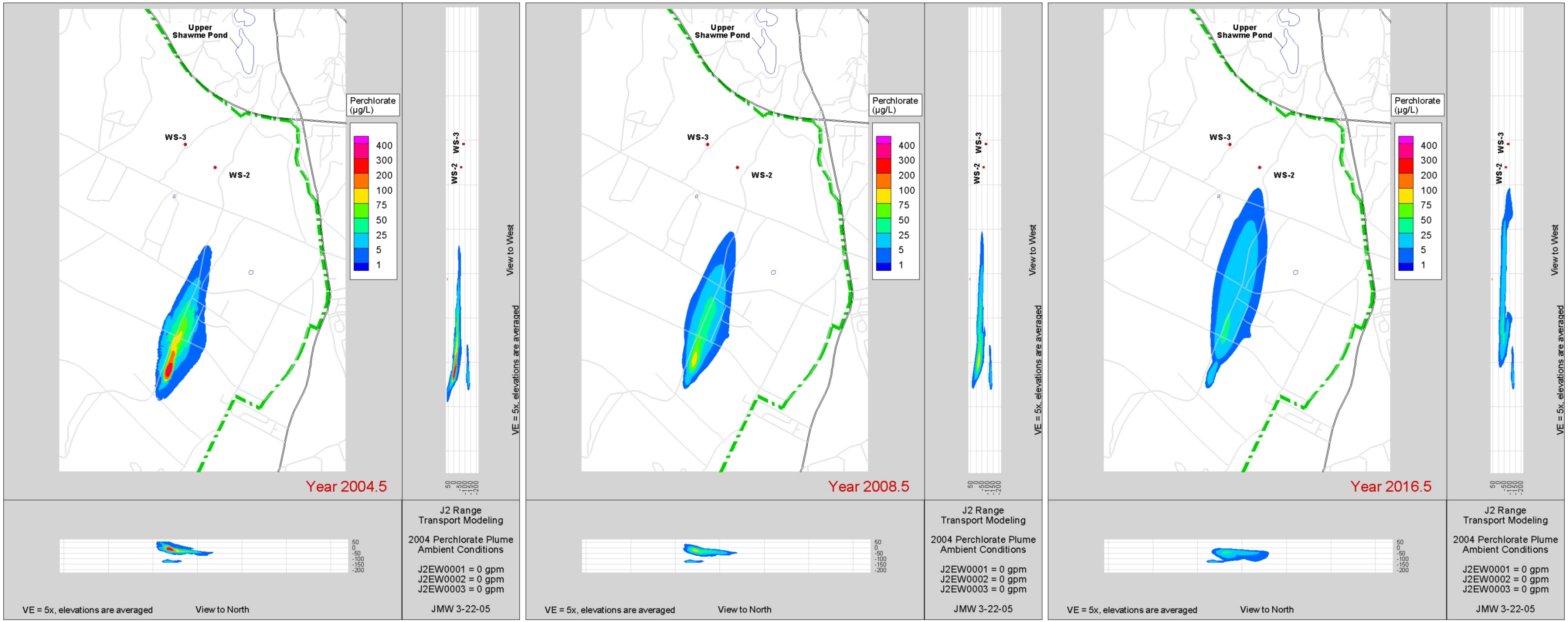
DRAFT
Jacobs
Bourne, Massachusetts

Scenario 25g_u Drawdown and
Mounding Contours — Model Layer 14

FIGURE
5-13

Y:/Ia_terc/Projects/35AY53/01/20050330/ArcGIS
Run25G_U_DD_MD2.mxd
March 30, 2005 NZehms Checked by JDefenderfer

Impact Area
Groundwater Study Program



Legend

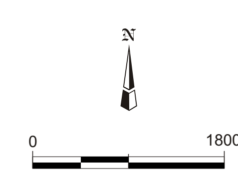
- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.



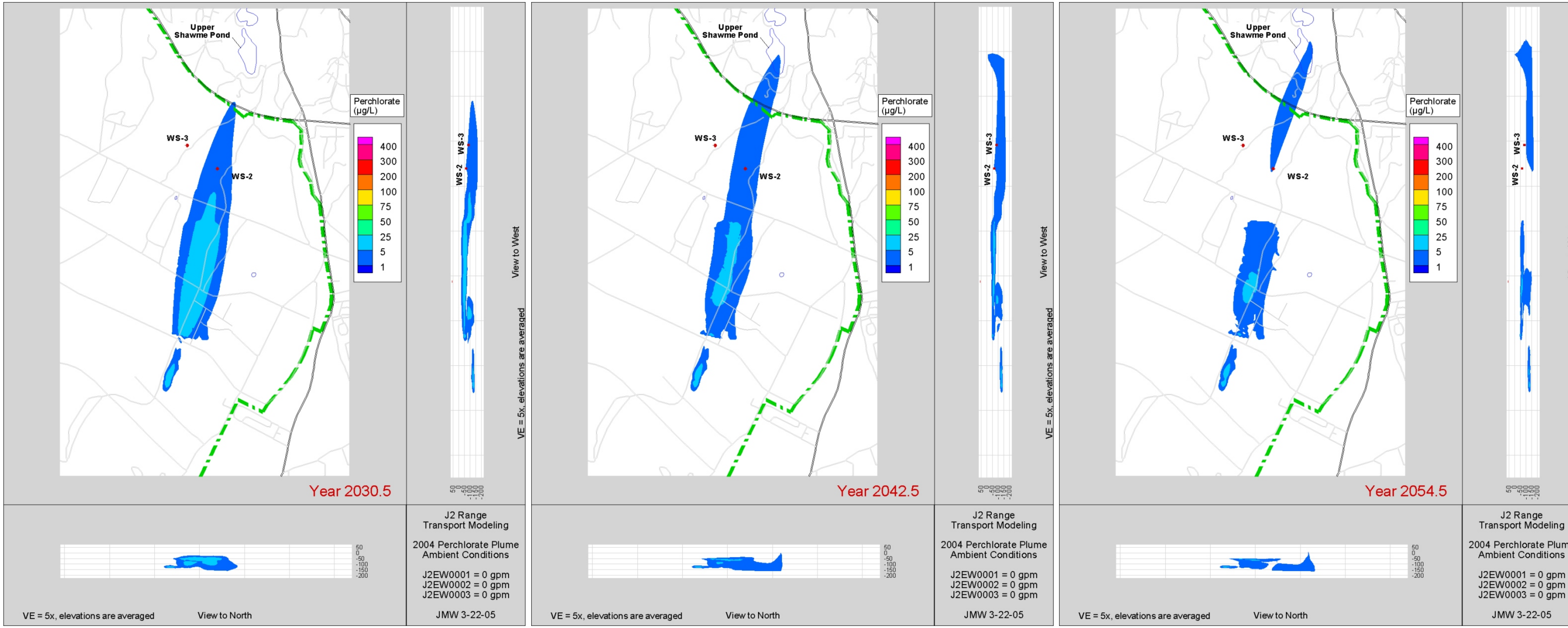
JACOBS

Model-Predicted Perchlorate Concentrations - J-2 Systems Ambient Conditions

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-14a Perc_AvgOp.cdr

Figure 5-14a



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800
Scale in Feet

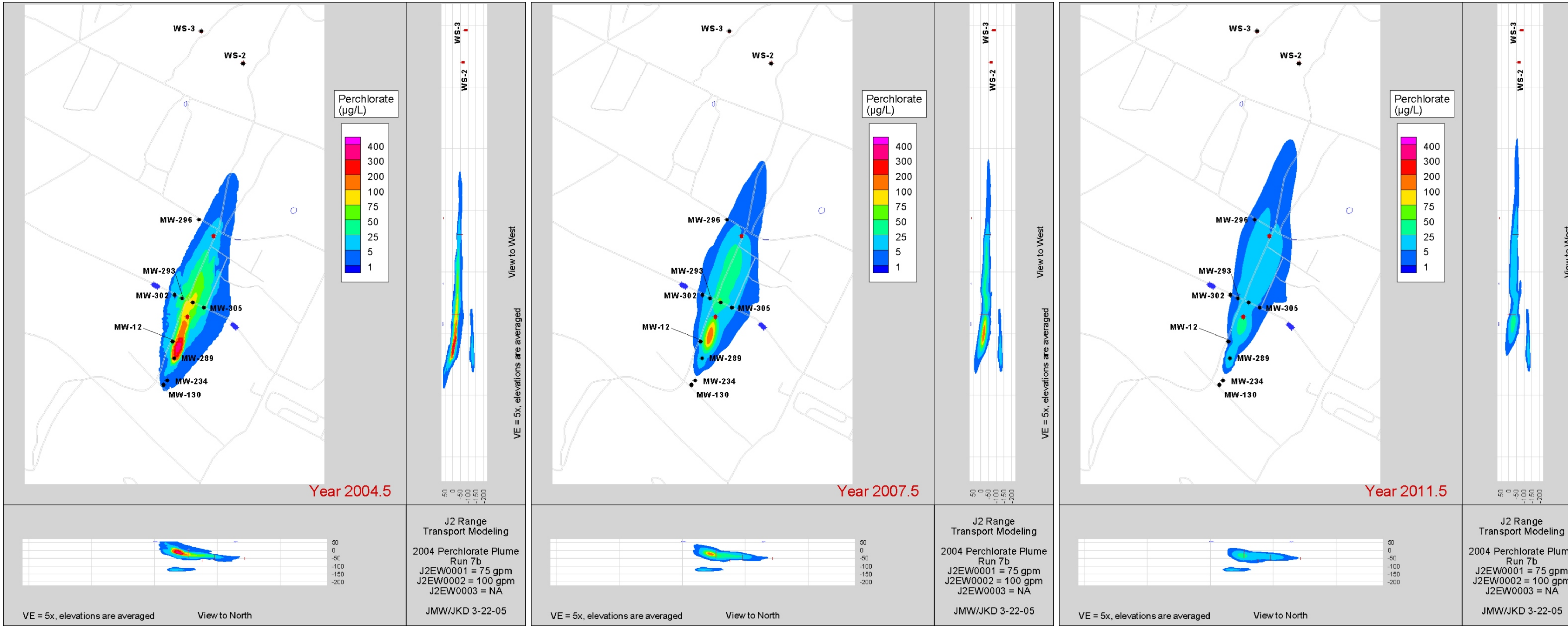
JACOBS

Model-Predicted Perchlorate Concentrations - J-2 Systems Ambient Conditions

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-14b Perc_AvgOp.cdr

Figure 5-14b



Legend

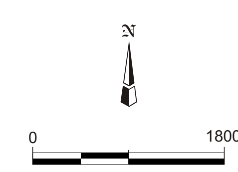
- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.



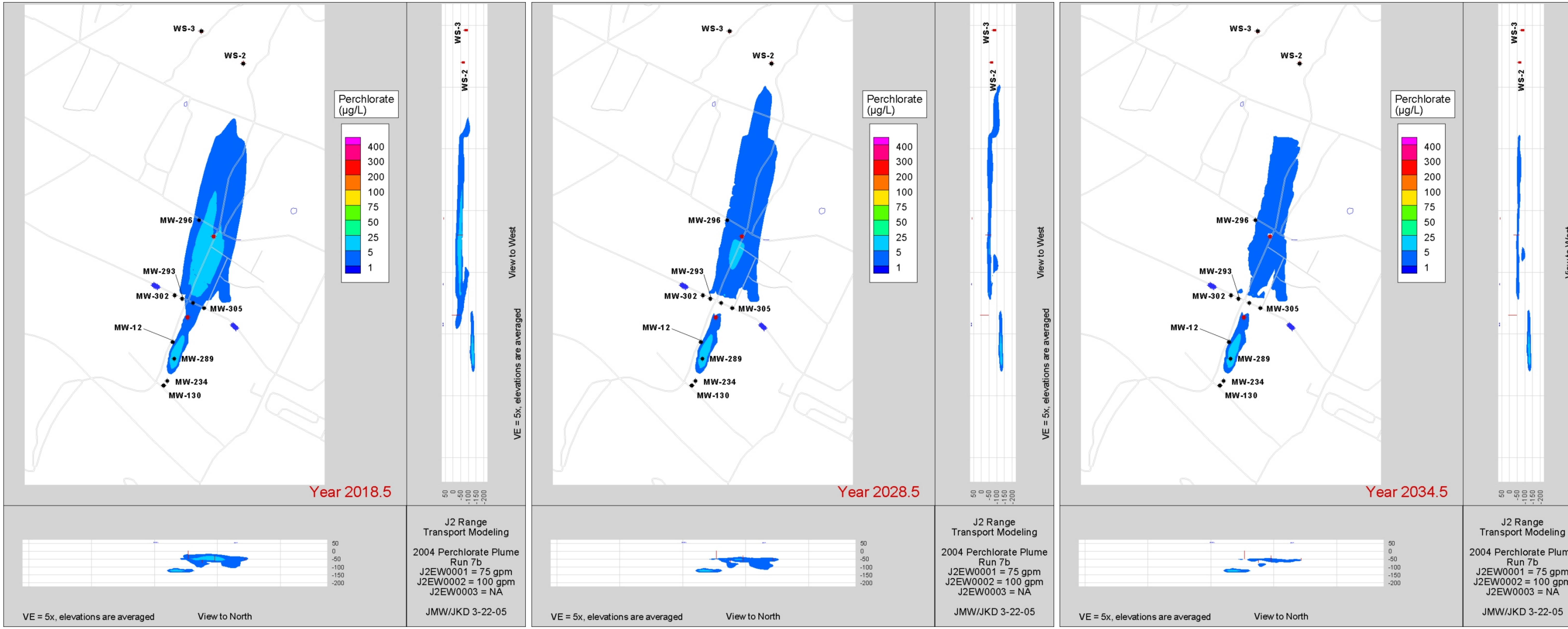
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 7b

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-15a Perc_Run7b.cdr

Figure 5-15a



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800
Scale in Feet

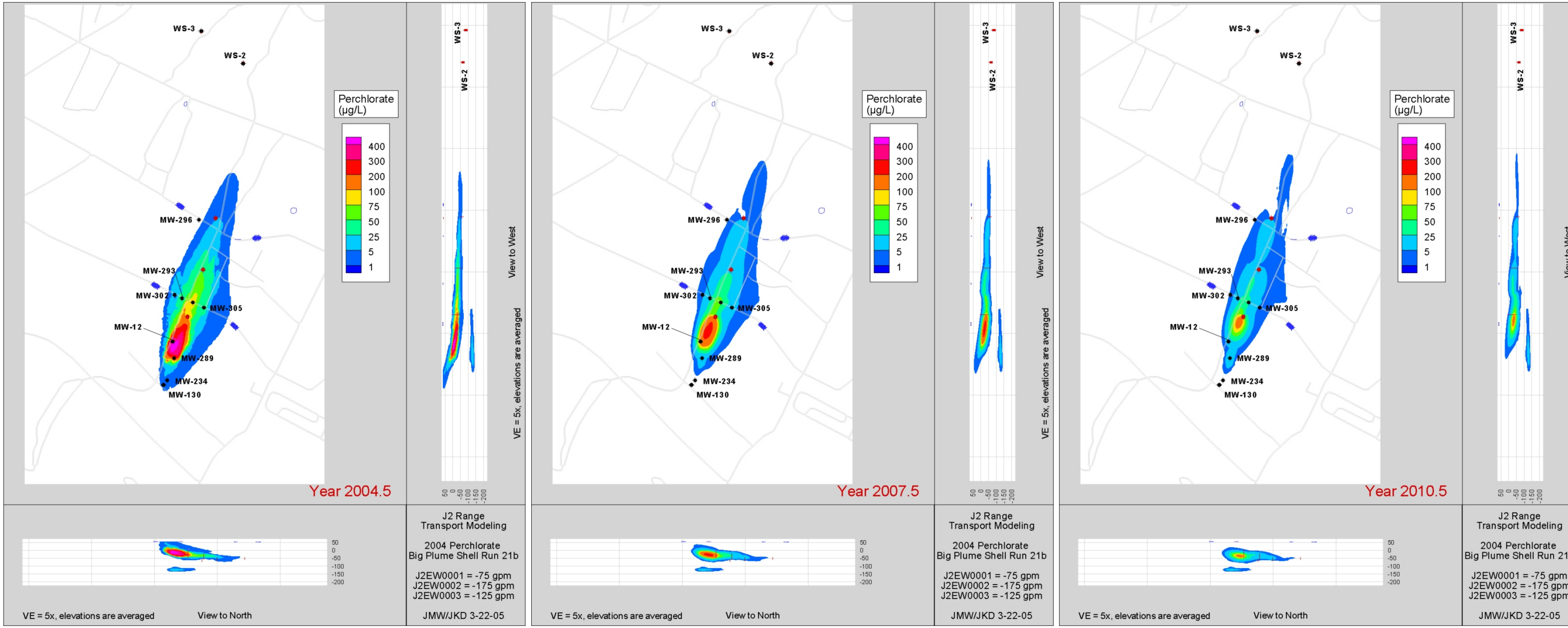
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 7b

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-15b Perc_Run7b.cdr

Figure 5-15b



Legend

Extraction Well

Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800

Scale in Feet

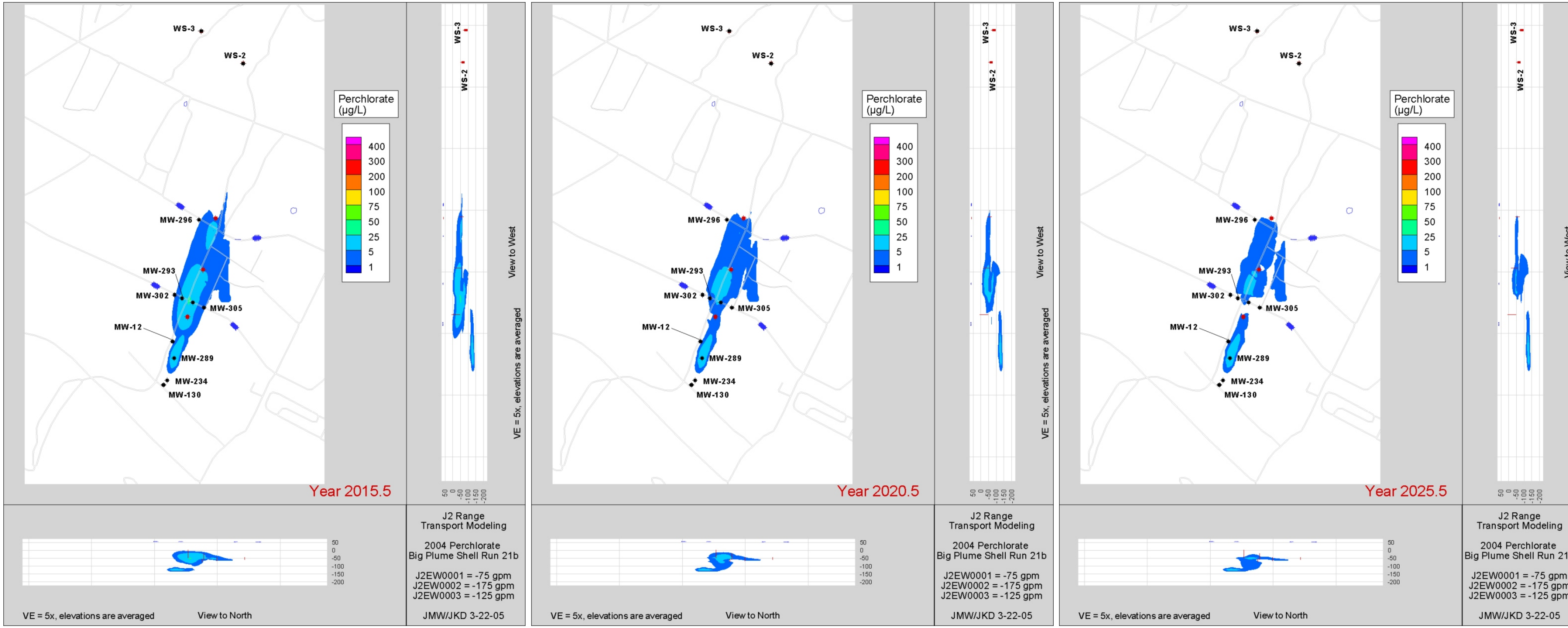
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 21b Sensitivity Analysis

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-16a Perc_Run21b_Exp_Mass.cdr

Figure 5-16a



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800

Scale in Feet

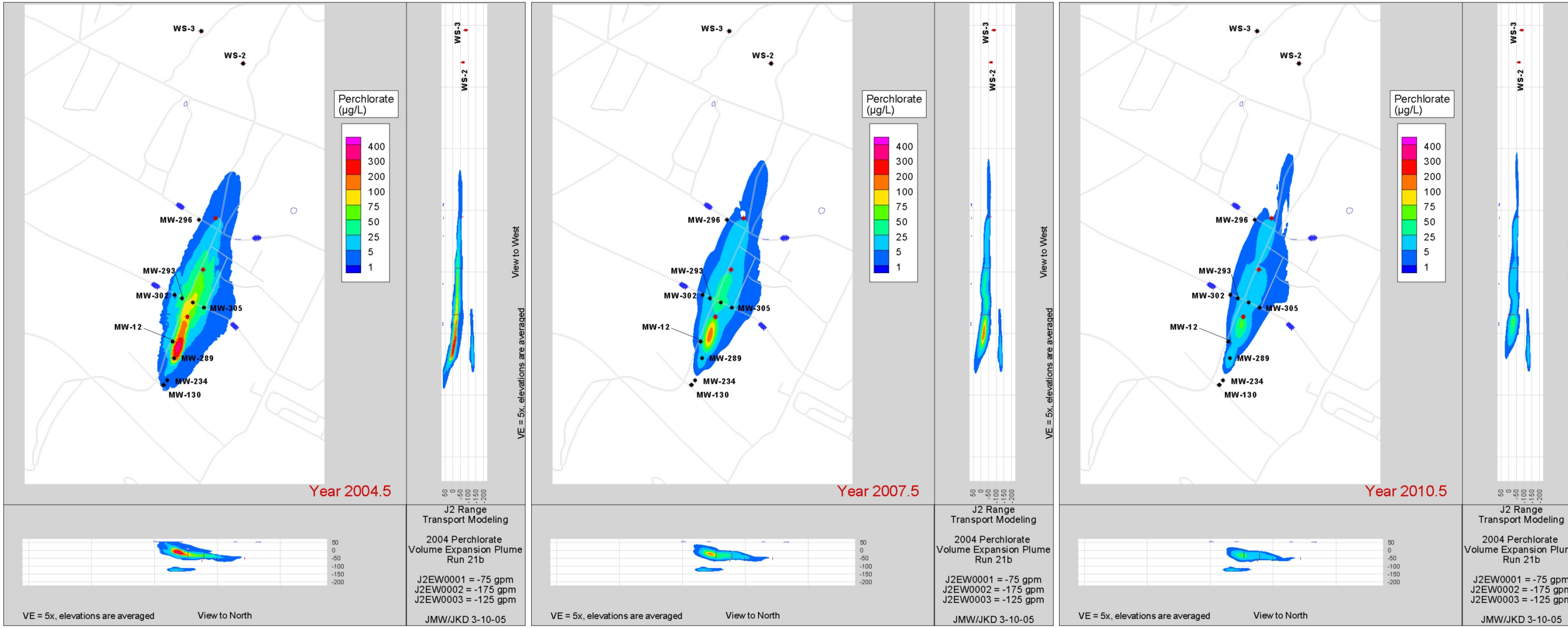
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 21b Sensitivity Analysis

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-16b Perc_Run21b_Exp_Mass.cdr

Figure 5-16b



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

0 1800
Scale in Feet

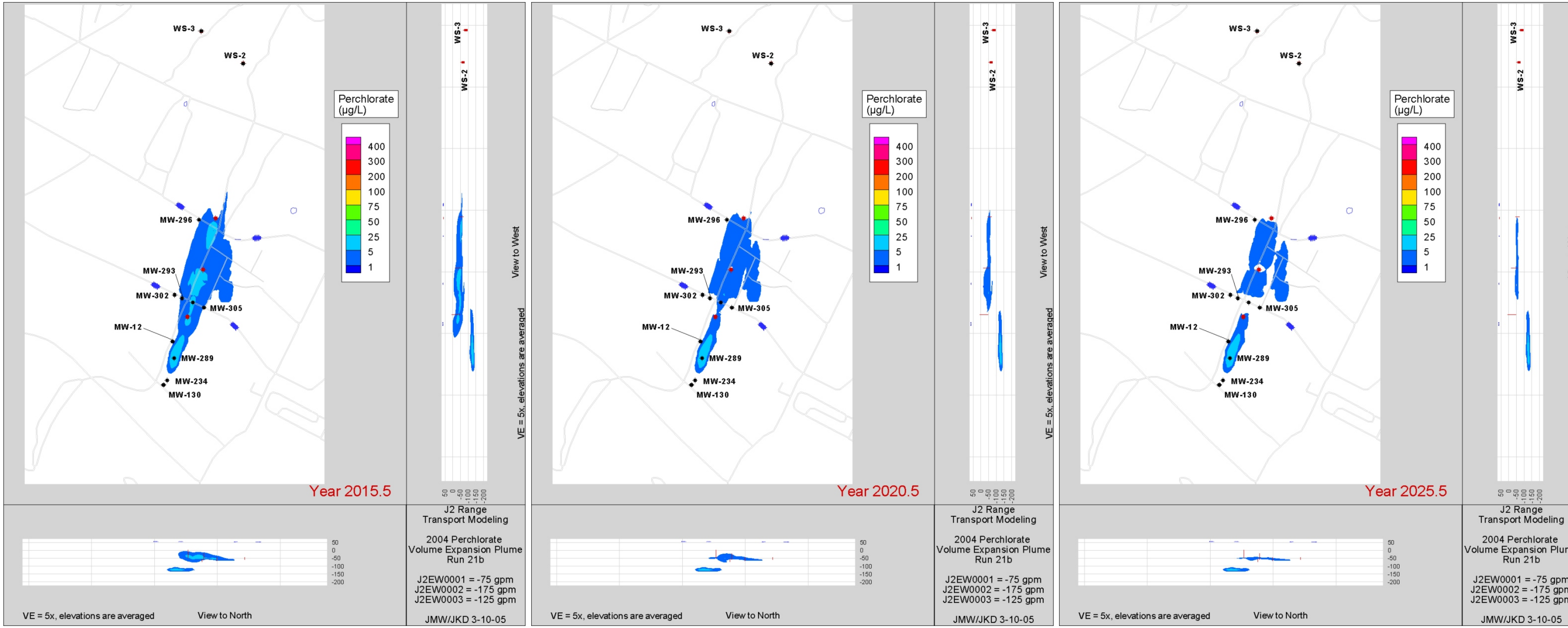
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 21b Expanded Volume Plume Sensitivity

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-17a Perc_Run21b_Exp_Mass.cdr

Figure 5-17a



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800
Scale in Feet

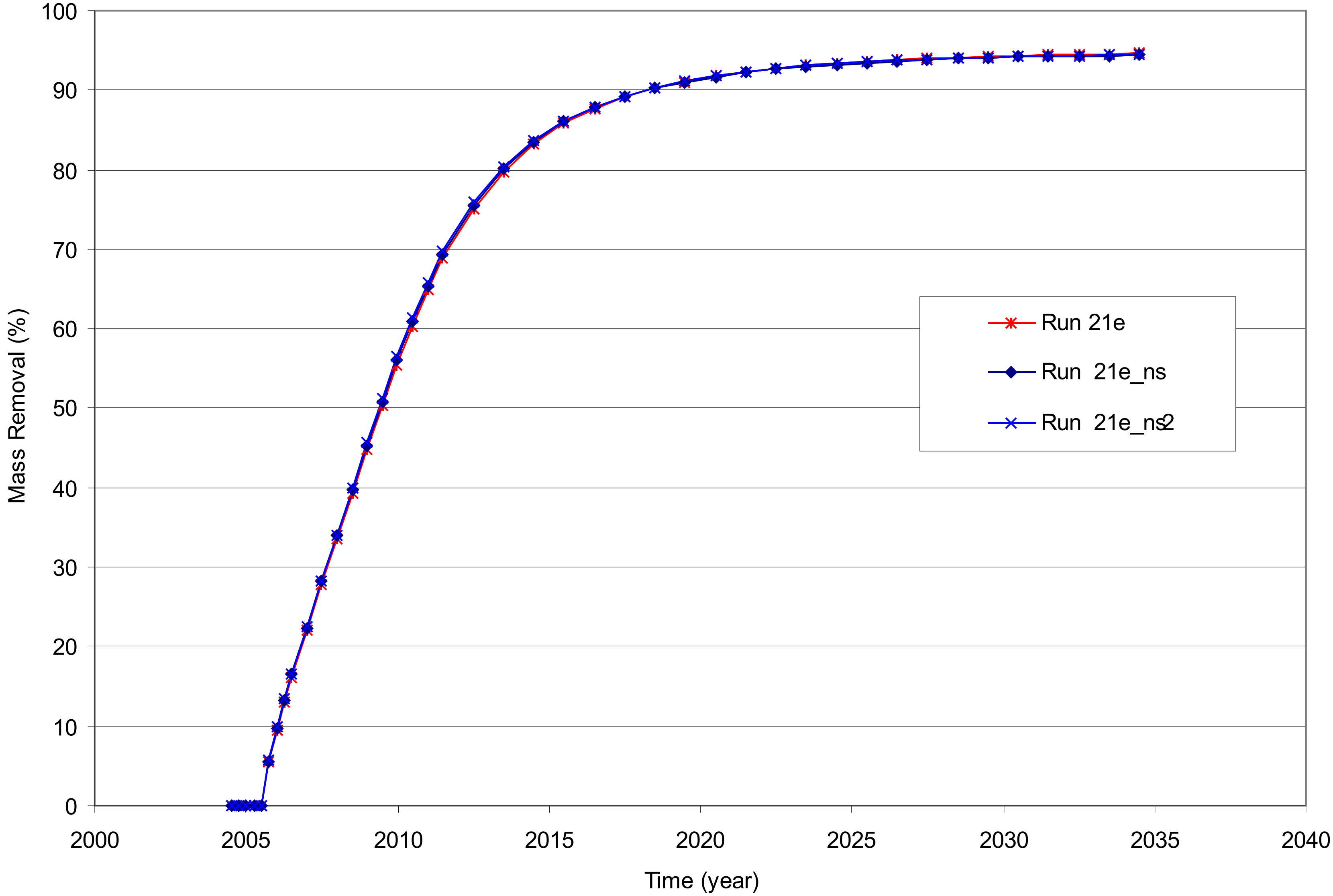
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 21b Expanded Volume Plume Sensitivity

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-17b Perc_Run21b_Exp_Vol.cdr

Figure 5-17b



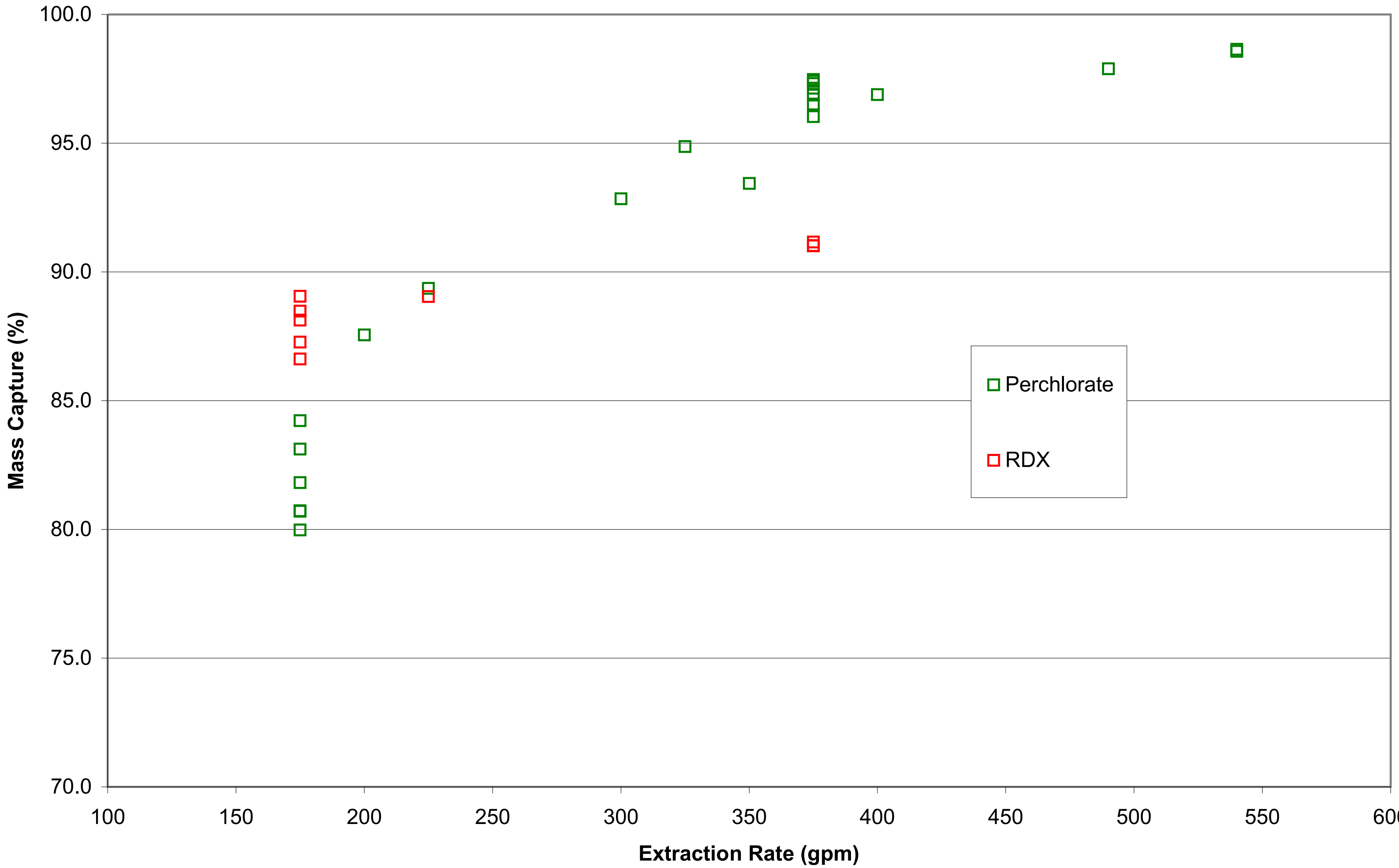
Impact Area Groundwater Study Program

Model-Predicted Perchlorate Mass Capture - Varying Screen Locations or Lengths - Scenario 21e

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/10/05 DMF
Fig5-18 Perc_Mass_Capt.cdr

Figure 5-18



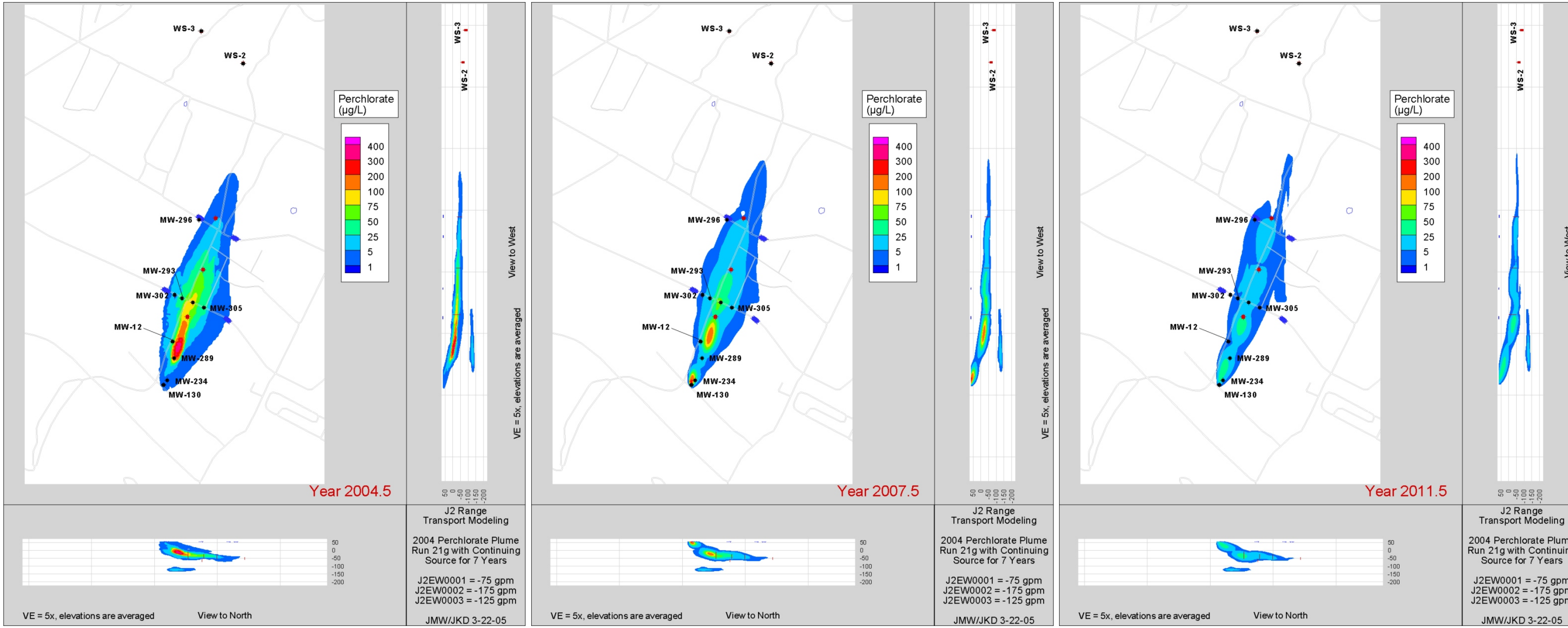
Impact Area Groundwater Study Program

Model-Predicted RDX and Perchlorate Mass Capture for Various Scenario Flow Rates

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/10/05 DMF
Fig5-19 Perc_Mass_Capt_vflow.cdr

Figure 5-19



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

0 1800
Scale in Feet

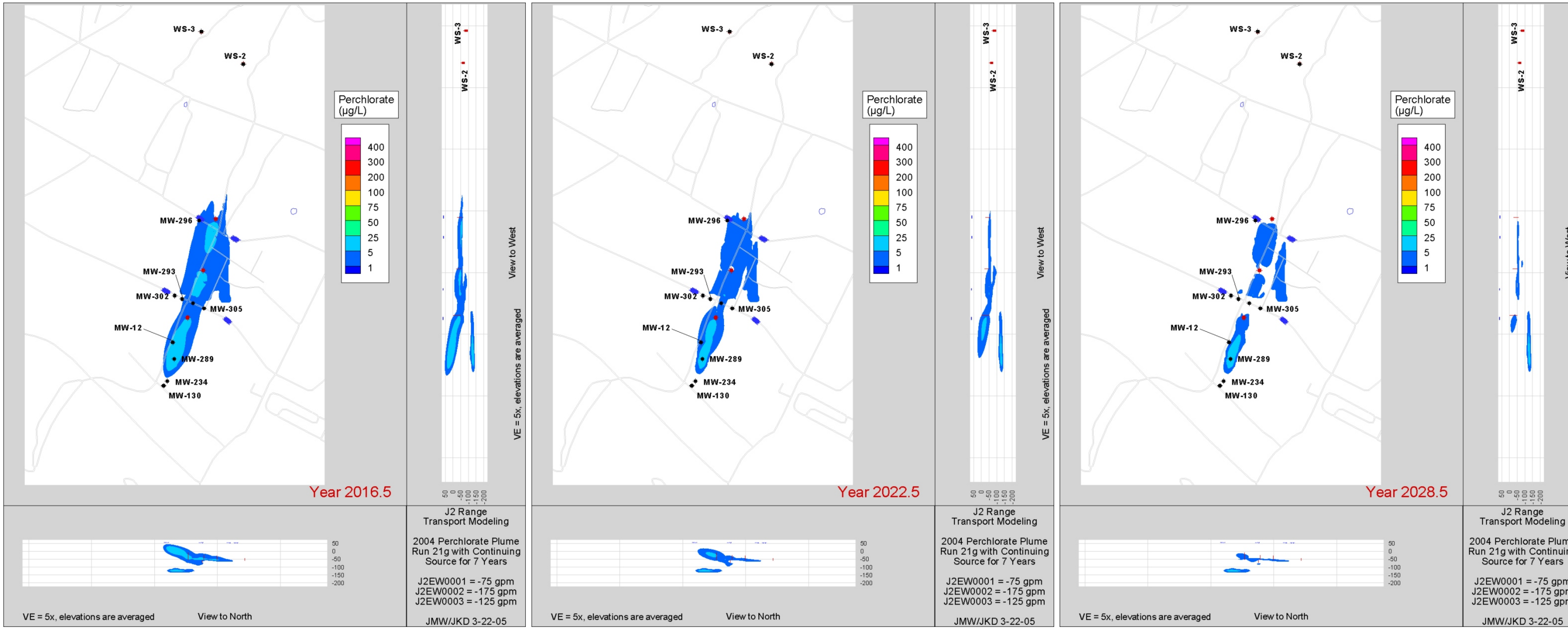
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 21g with Simulated Continuing Source

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-20a Perc_Run25g_Cont_Src.cdr

Figure 5-20a



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800
Scale in Feet

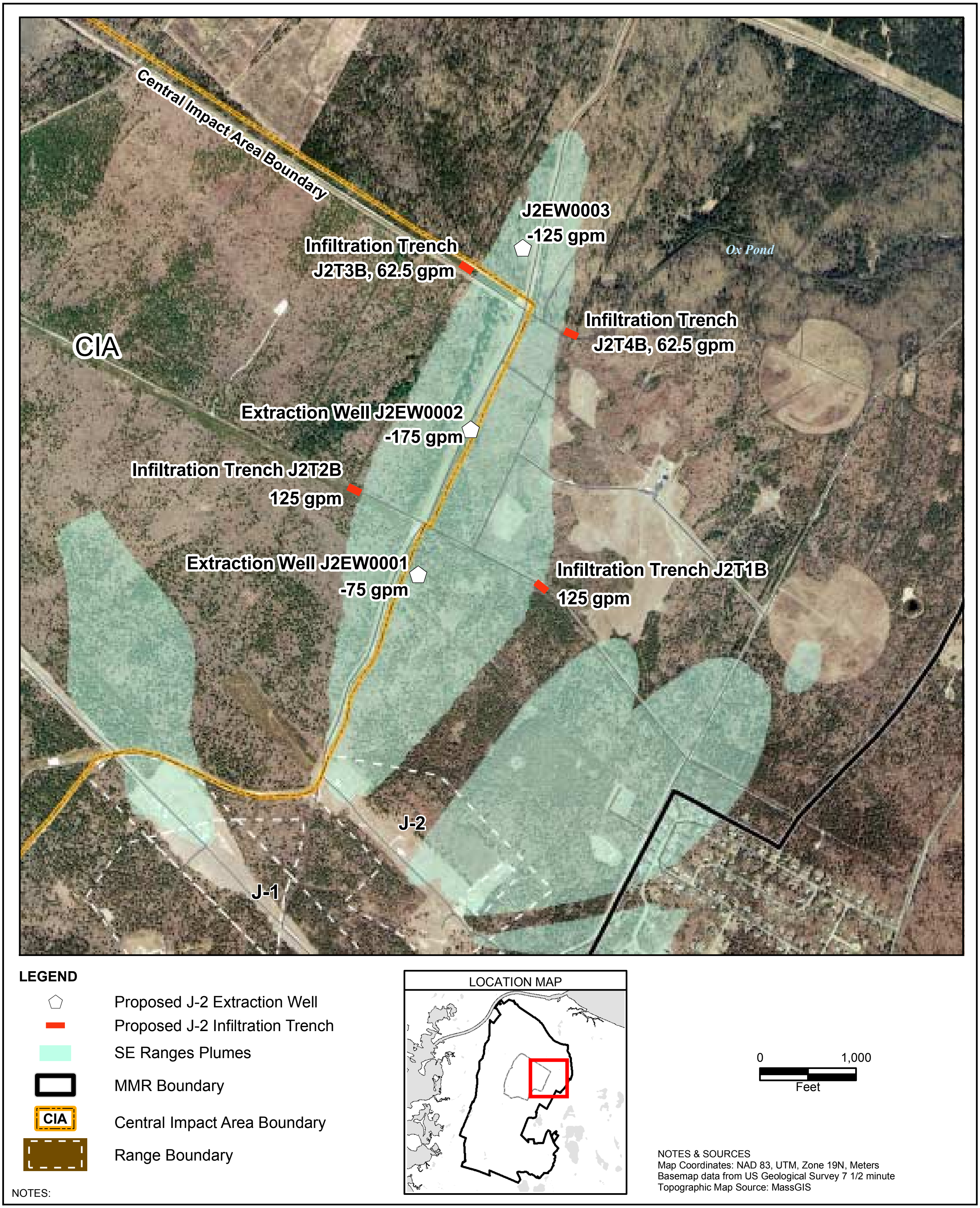
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 21g with Simulated Continuing Source

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-20b Perc_Run25g_Cont_Src.cdr

Figure 5-20b



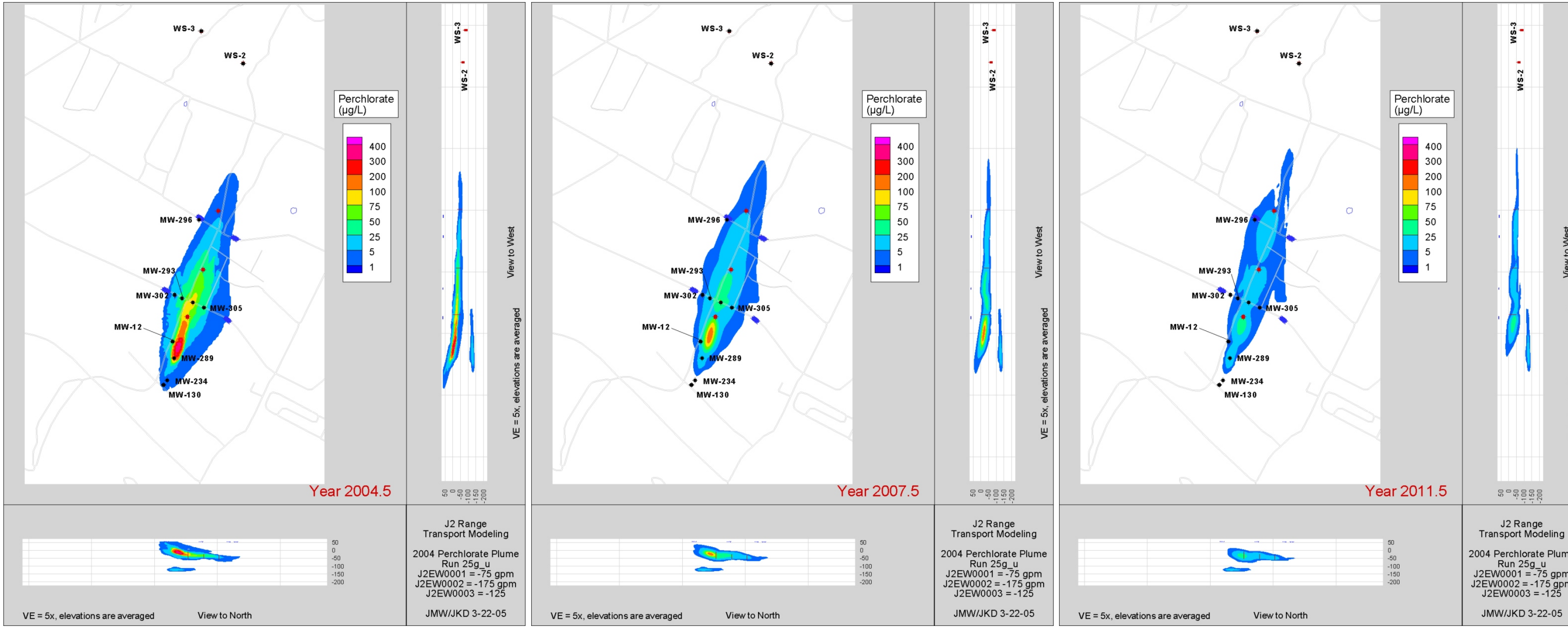
Jacobs
Bourne, Massachusetts

J-2 Scenario 25g_u — Proposed Extraction Well and Infiltration Trench Locations and Flow Rates

FIGURE 5-21

Y:/la_terc/Projects/35AY53/01/20050330/ArcGIS
Run25G_U_well_config2.mxd
March 30, 2005 NZehms Checked by JDefenderfer

Impact Area Groundwater Study Program



Legend

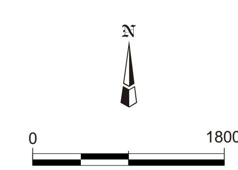
- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 µg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.



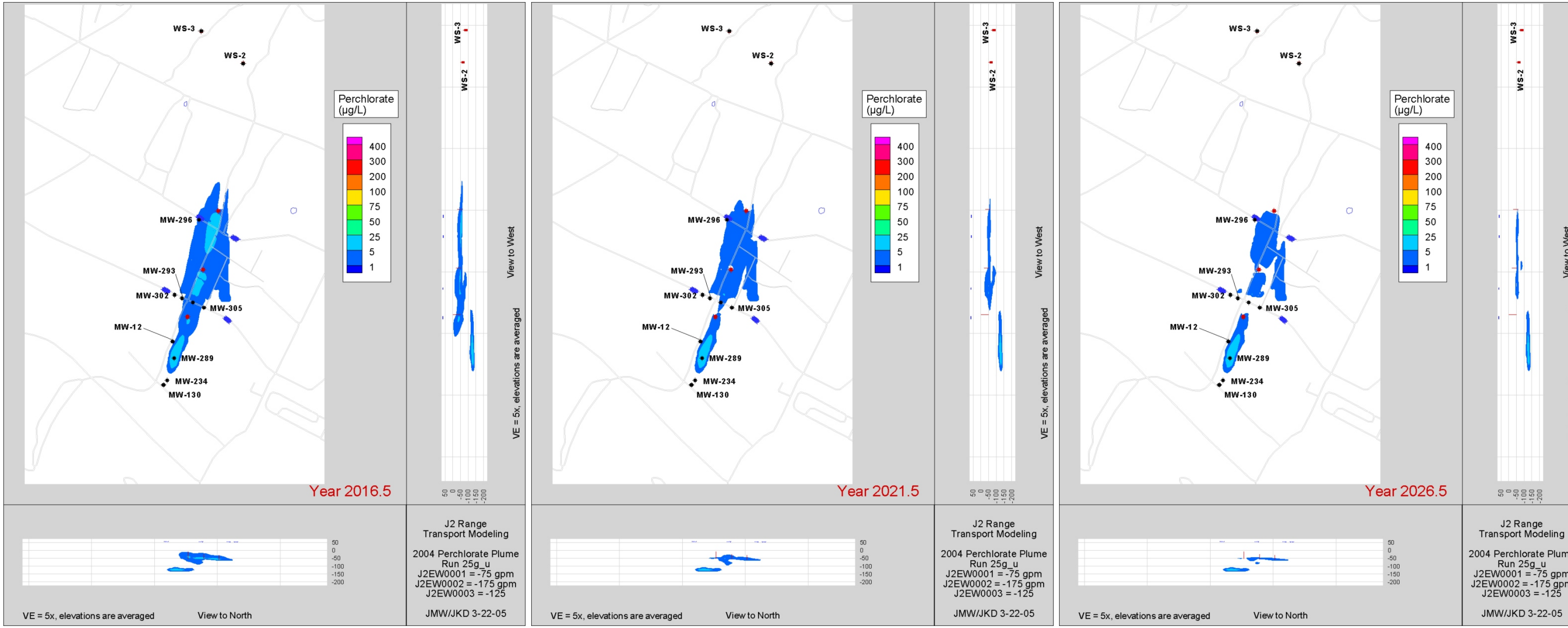
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 25g_u

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-22a Perc_Run25g_u.cdr

Figure 5-22a



Legend

- Extraction Well
- Reinjection Well

Notes

State of MA guidance level = 1 μg/L

Decay half-life = 0

Three views are shown for each frame: a plan view, a view to the west and a view to the north. In each view, the maximum concentration in the plume is depicted, regardless of its three-dimensional depth relative to the viewport.

N

0 1800
Scale in Feet

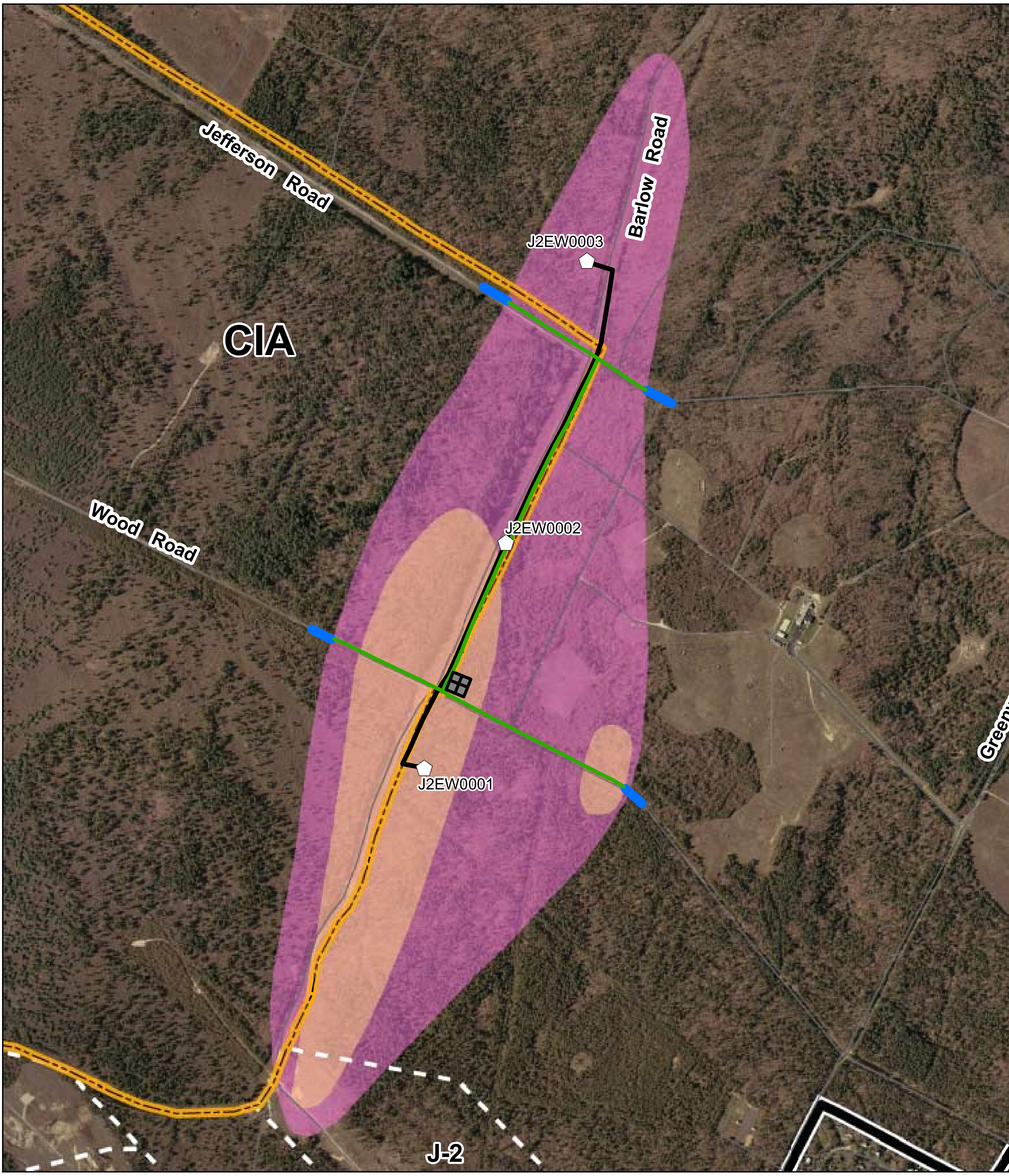
JACOBS

Model-Predicted Perchlorate Concentrations - Scenario 25g_u

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/22/05 DMF
Fig5-22b Perc_Run25g_u.cdr

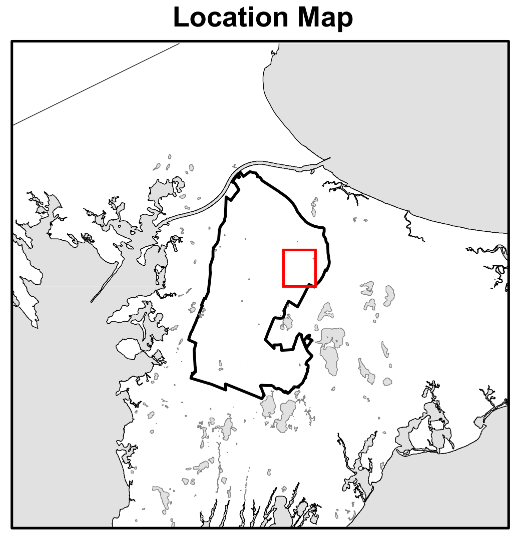
Figure 5-22b



LEGEND

- Proposed Extraction Wells
- Influent Piping
- Effluent Piping
- Infiltration Trench
- Road Centerline
- Treatment Facility (Four 100-gpm Treatment Units)
- J-2 North Perchlorate Plume
- J-2 North RDX Plume
- MMR Boundary
- CIA Central Impact Area Boundary
- Range Boundary

Location Map



0 650 1,300
Feet

N

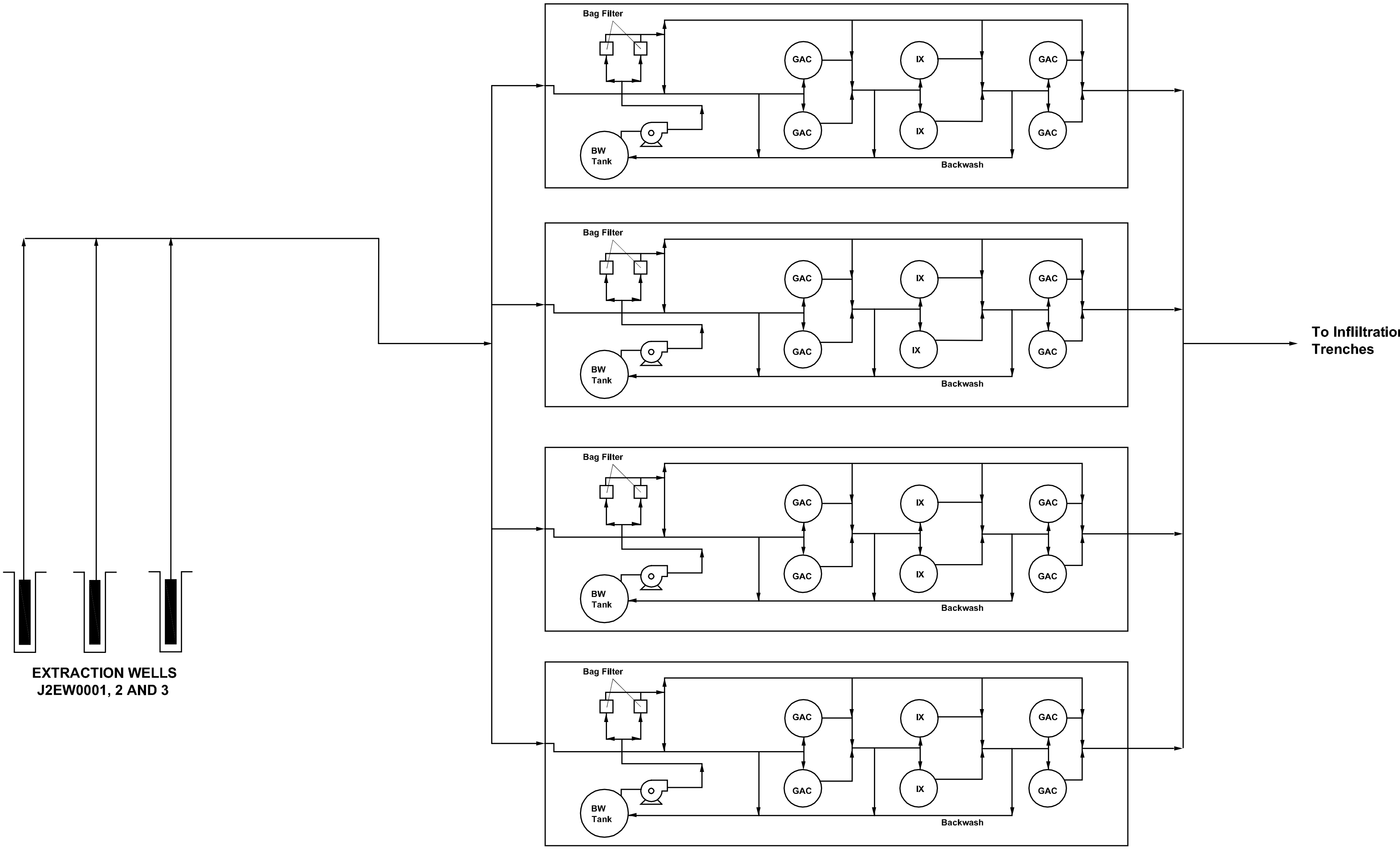
Proposed J-2 North Extraction Wells, Infiltration Trenches, and Treatment Plant Locations

FIGURE
5-23

JACOBS
Bourne, Massachusetts

JACOBS
Bourne, Massachusetts
Y:\IA_TERC\Projects\35AY53\01\20050330\ArcGIS
j2_per__rdx_ext_reinj_treatment2.mxd
March 30, 2005 jpiccuito Checked by

Impact Area Groundwater Study Program



Legend

GAC - granular activated carbon

IX - ion exchange

BW - back wash

JACOBS

J-2 North RRA GAC-IX-GAC Process Flow Diagram

Massachusetts Military Reservation
Cape Cod, Massachusetts

03/30/05 JP J2RRA_GAC_DESIGN2.dwg

Figure 5-24

TABLES

Table 3-1
Summary of J-2 Plume Constituent Screening

Analyte	Number of Samples	Number of Detects	Units	Minimum Detect	Average Result[1]	Maximum Detect	Region 9 Tap Water PRG	Number of results > PRG
HEXAHYDRO-1,3,5-TRINITRO-1,3,5-TRIAZINE (RDX)	228	32	µg/L	0.29	0.29	11	6.1E-01	23
OCTAHYDRO-1,3,5,7-TETRANITRO-1,3,5,7- TETRAZOCINE (HMX)	228	21	µg/L	0.29	0.13	3.8	1.8E+03	0
PERCHLORATE	163	46	µg/L	0.41	6.27	140	3.6E+00	25

Notes:
[1] Average calculated using 0.5 times the detect limit for results reported as nondetect.

PRG = Preliminary Remediation Goals
µg/L = micrograms per liter

Table 4-1
Summary of Regulatory Considerations
J-2 Range North Groundwater RRA Plan

PROVISION	SYNOPSIS	ACTION TO BE TAKEN IN CONSIDERATION
SDWA MCLs, 40 CFR 141.61 – 141.63	The EPA has promulgated SDWA MCLs (40 CFR 141-143) that are enforceable standards for public drinking water supplies. The standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health.	Cleanup goals established for the J-2 actions considered federal MCLs.
MA Drinking Water Regulations, 310 CMR 22.00	These standards establish Massachusetts MCLs (MMCLs) for public drinking water systems.	Cleanup goals established for the J-2 actions considered Massachusetts MCLs (MMCLs) (310 CMR 22.00 et. seq.).
SDWA Sole Source Aquifer Program, Section 1424(e) of the SDWA, 47 FR 30282	Pursuant to Section 1424(e) of the Safe Drinking Water Act, the EPA has determined that the Cape Cod aquifer is the sole or principal source of drinking water for Cape Cod, Massachusetts.	Groundwater would be treated in accordance with Drinking Water Standards and Health Advisories before recharge so that this action will not contaminate the aquifer through a recharge zone.
SDWA Underground Injection Control Program, 40 CFR 114, 146, 147, 1000	Underground Injection Control Program (40 CFR 114, 146, 147, 1000) regulations outline minimum program and performance standards for underground injection wells and prohibit any injection that may cause a violation of any primary drinking water regulation in the aquifer. These regulations are administered by the State. See description of State regulations below.	Extracted groundwater will be treated to levels at or below federal and state primary drinking water standards (i.e., MCLs) to ensure that discharges through infiltration to the receiving aquifer will not cause any violation of these standards in the aquifer.
MA Underground Injection Control Program, 310 CMR 27.00 et seq.	These regulations prohibit the injection of fluid containing any pollutant into underground sources of drinking water where such pollutant will or is likely to cause a violation of any state drinking water standard, or adversely affect the health of persons.	Extracted groundwater will be treated to levels at or below federal and state primary drinking water standards (i.e., MCLs) to ensure that discharges through infiltration to the receiving aquifer will not cause any violation of these standards in the aquifer.

Table 4-1
Summary of Regulatory Considerations
J-2 Range North Groundwater RRA Plan

PROVISION	SYNOPSIS	ACTION TO BE TAKEN IN CONSIDERATION
Resource Conservation and Recovery Act (RCRA) Identification of Hazardous Waste, 40 CFR 261.20 - 261.24	These requirements identify the characteristics and maximum concentrations of contaminants at which the waste would be considered characteristically hazardous waste. If a waste is determined to be hazardous, it must be managed in accordance with 40 CFR 261 - 268 requirements.	Testing of any solid waste generated will be performed in accordance with these requirements. If any solid wastes are determined to be hazardous, they will be managed in accordance with these regulations and disposed of in a RCRA Subtitle C permitted TSD facility.
Hazardous Waste Management Regulations – Requirements for Generators, 310 CMR 30.000 et seq.	A person who generates solid waste must determine whether the waste is hazardous using various methods, including the TCLP method, or application of knowledge of the hazardous characteristics of the waste based on information regarding the materials or processes used. If a waste is determined to be hazardous, it must be managed in accordance with 310 CMR 30.000 et seq.	Testing of any solid waste generated will be performed in accordance with these requirements. If any solid wastes are determined to be hazardous, they will be managed in accordance with these regulations and disposed of in a RCRA Subtitle C permitted TSD facility.
Solid Waste Management Regulations (RCRA Subtitle D), 310 CMR 19.000 et seq.	If a waste is determined to be a solid waste, it must be managed in accordance with the state regulations at 310 CMR 19.000 et seq.	Any solid wastes generated and determined to be non-hazardous will be managed in accordance with these regulations and disposed of appropriately.
Hazardous Waste Operations and Emergency Response, 29 CFR 1910.120	These regulations describe training, monitoring, planning, and other activities to protect the health of workers performing hazardous waste operations.	These worker protection standards would be followed to protect the health of workers if any primary or secondary wastes are determined to be RCRA characteristically hazardous.

Table 4-1
Summary of Regulatory Considerations
J-2 Range North Groundwater RRA Plan

PROVISION	SYNOPSIS	ACTION TO BE TAKEN IN CONSIDERATION
Safety and Health Regulations for Construction, 29 CFR 1926, Subpart P	These regulations define safety requirements for construction and excavation activities.	Work crews will fulfill requirements, as applicable, including: • confirming absence of subsurface utilities (digsafe); • egress from excavations greater than four feet deep; • protection from falling loads and loose rock and soil; • use of warning systems for mobile equipment; and • protection from cave-in (side slopes) for employees in an excavation.
CWA NDPES Stormwater Discharge Requirements, 40 CFR 122.26	Establishes requirements for stormwater discharges associated with construction activities that result in a land disturbance of equal to or greater than one acre of land. The requirements include good construction management techniques; phasing of construction projects; minimal clearing; and sediment, erosion, structural, and vegetative controls to mitigate stormwater run-on and runoff.	If stormwater runoff associated with this rapid response action discharges to a surface water body, including wetlands, the runoff will be controlled in accordance with these requirements.
Stormwater Discharge Requirements, 314 CMR 3.04 and 314 CMR 3.19	Requires that stormwater discharges associated with construction activities be managed in accordance with the general permit conditions of 314 CMR 3.19 so as not to cause a violation of Massachusetts surface water quality standards in the receiving surface water body (including wetlands).	If stormwater runoff associated with remedial action construction, operation or maintenance activities discharges to a surface water body, including wetlands, the runoff will be controlled in accordance with these requirements.
Massachusetts Air Pollution Control Regulations [310 CMR 6.00 – 7.00]	These regulations set emission limits necessary to attain ambient air quality standards.	Engineering controls, such as dust suppression, would be used as necessary to comply with these regulations for particulate emissions during site construction activities.

Notes (relating to Table 4-1):

CFR = *Code of Federal Regulations*
CMR = *Commonwealth of Massachusetts Regulations*
COC = contaminant of concern
CWA = Clean Water Act
DOD = U.S. Department of Defense
EO = Executive Order
EPA = Environmental Protection Agency
ETI = extraction, treatment, and infiltration
FR = Federal Register
MA = Massachusetts
MADEP = Massachusetts Department of Environmental Protection
MCL = maximum contaminant level
MCP = Massachusetts Contingency Plan
M.G.L. = Massachusetts General Law
MMCL = Massachusetts maximum contaminant level
MMR = Massachusetts Military Reservation
NPDES = National Pollutant Discharge Elimination Act
RCRA = Resource Conservation and Recovery Act
RRA = rapid response action
SDWA = Safe Drinking Water Act
TCLP = Toxicity Characteristic Leaching Procedure
TSD = treatment, storage, and disposal

Table 5-1
J-2 North Groundwater RRA Plan
Groundwater Age Dating - Model-Predicted and Observed Travel Times

Monitoring Well ID	Midscreen Elevation (ft)	Estimated Age from USGS Tritium Data (Years)	Estimated Age from J-2 Model Particle Tracking (Years)
58MW0010B	-32.89	36.00	10.50
58MW0011D	13.33	14.40	6.00
90MW0022	-9.4	24.80	16.00
WL18M1	-70.68	31.10	28.50
WL01M1	-35.89	30.80	44.50
WL01M2	24.53	9.60	7.00
WL02M1	-7.12	11.90	15.50
WL02M2	34.88	4.50	4.50
WL05M1	-28.29	20.20	18.50
WL05M2	11.71	27.20	8.00
WL07M1	-65.70	60.80	85.00
WL07M2	4.30	13.70	10.50

Notes:
ft = feet

Table 5-2
J-2 North Groundwater RRA Plan
J-2 North 2004 Plume Shell *KT3D* Grid Properties

Property	Value
Origin easting (NAD27 SPC ft)	867,540
Origin northing (NAD27 SPC ft)	258,020
Origin elevation (ft msl)	-180
Cell X (easting) length (ft)	40
Cell Y (northing) length (ft)	40
Cell Z (elevation) length (ft)	5
Grid X number of cells	92
Grid Y number of cells	220
Grid Z number of cells	51
Total number of cells	1,032,240

Notes:

KT3D : Deutsch, C.V., and A.G. Journel. 1998. *GSLIB Geostatistical Software Library and User's Guide.* New York, NY.

ft = feet

msl = mean sea level

NAD27 = North American Datum of 1927

SPC = State Plane Coordinates

Table 5-3
J-2 North Groundwater RRA Plan
J-2 North 2004 Plume Shell *KT3D* Kriging Parameters

Zone	Azimuth[1] (°)	Dip (°)	Search Ellipsoid Radii[2] (ft)
J-2 RDX			
North	18	0	600,180,6
South	15	-2	600,180,6
Upgradient	18	-3.5	600,180,6
Deep[3]	18	0	600,180,6
J-2 Perchlorate			
North	18	0	600,180,6
South	18	-2	600,180,6
Upgradient	18	-3.5	600,180,6
Deep[3]	18	0	600,180,6

Notes:

[1] North = 0°, increasing clockwise to 360° (e.g., 18° = N18E)

[2] Search Ellipsoid Radii are given as longitudinal, transverse, and vertical kriging ranges

[3] The Deep kriging zone was used for grid points below the Upgradient and South kriging zones (Figure 5-4) and below kriging grid layer 35 (layers 36-51; below about –105 ft msl)

KT3D : Deutsch, C.V., and A.G. Journel. 1998. *GSLIB Geostatistical Software Library and User's Guide.* New York, NY.

° = degrees

ft = feet

RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine

Table 5-4
J-2 North Groundwater RRA Plan
J-2 North 2004 Plume Shell Summary

Shell	Lowest Concentration [1] (Cut-Off) (µg/L)	Plume Water Volume [2, 3] (10^6 ft^3)	Maximum Concentration in Plume Shell (µg/L)	Maximum Concentration in Model Grid (µg/L)	Total Mass in Plume Shell (kg)	Mass Above Cut-Off in Plume Shell (kg)	Mass in Model Grid (kg)	Fraction of Mass in Model Grid[4] (percent)
J-2 North RDX	0.25	17.3	11.1	9.7	0.77	0.75	0.76	99.6%
J-2 North Perchlorate	0.35	90.7	370	370	29.5	29.4	29.5	100.0%
J-2 North Perchlorate	1.00	68.3	370	370	29.5	29.0	29.5	100.0%

Notes:

[1] The lowest concentration in the plume shell, as identified by the estimated detection limit, and alternatively for the perchlorate plume shell, the MADEP interim guidance level for perchlorate of 1.00 µg/L

[2] Volume above the specified Lowest Concentration

[3] A porosity of 30 percent was assumed

[4] Aqueous Mass in Model Grid relative to Total Mass in Plume Shell, rather than the mass above the specified Lowest Concentration (Cut-Off)

ft^3 = cubic feet

kg = kilograms

RDX = hexahyrdo-1,3,5-trinitro-1,3,5-triazine

µg/L = micrograms per liter

Table 5-5

J-2 Range RRA Modeling - Pumping Well Scenarios

Pumping Scenario	Constituent Simulated	J-2 Pumping Wells Flow Rates			Total Flow Rate (gpm)	Perchlorate Plume Shell Used			Total Number of Simulations
		J3EW0001	J3EW0002	J3EW0003		Base-Case	Mass-Exp	Detection Limit	
Scen 1a	RDX/Perc	100	75	NA	175	x			2
Scen 2a	RDX/Perc	100	75	NA	175	x			2
Scen 2b	RDX/Perc	100	75	NA	175	x			2
Scen 2c	RDX/Perc	100	75	NA	175	x			2
Scen 2d	RDX/Perc	100	75	NA	175	x			2
Scen 3a	RDX/Perc	100	75	50	225	x			2
Scen 4b	RDX/Perc	75	100	0	175	x			2
Scen 5b	Perc	100	75	NA	175	x			1
Scen 6b	Perc	100	75	NA	175	x			1
Scen 7b	Perc	75	100	NA	175	x			1
Scen 8a	Perc	75	100	50	225	x			1
Scen 8b	Perc	75	100	50	225	x			1
Scen 9b	Perc	75	125	NA	200	x			1
Scen 10b	Perc	125	175	100	400	x			1
Scen 11b	Perc	125	100	75	300	x			1
Scen 12b	Perc	100	125	100	325	x			1
Scen 13b	Perc	125	200	125	450	x			1
Scen 14b	Perc	75	175	125	375	x			1
Scen 15b	Perc	note[1]	note[1]	note[1]	350	x			1
Scen 16b	Perc	75	175	125	375	x			1
Scen 17b	Perc	75	200	100	375	x			1
Scen 18b	Perc	75	175	125	375	x			1
Scen 19b	Perc	note[2]	note[2]	note[2]	490	x			1
Scen 20b	Perc	note[3]	note[3]	note[3]	540	x			1
Scen 21b	Perc	75	175	125	375	x	x	x	3
Scen 21e	Perc	75	175	125	375	x			1
Scen 21e_ns	Perc	75	175	125	375	x			1
Scen 21e_ns2	Perc	75	175	125	375	x			1
Scen 21g	Perc	75	175	125	375	x			1
Scen 21g_u	Perc	75	175	125	375	x			1
Scen 21g_m	Perc	75	175	125	375	x			1
Scen 21g_d	Perc	75	175	125	375	x			1
Scen 22b	Perc	75	175	125	425*	x			1
Scen 23b	Perc	note[4]	note[4]	note[4]	540	x			1
Scen 24b	Perc	110	175	125	410	x	x		2
Scen 25g	RDX/Perc	75	175	125	375	x			2
Scen 25g_u	RDX/Perc	75	175	125	375	x			2
Scen 25g_ua	RDX/Perc	87.5	87.5	NA	175	x			2
Scen 25 g_da	Perc	NA	87.5	87.5	175	x			1
Scen 26g	Perc	75	175	125	375	x			1
Scen 27g	RDX	90	0	0	90	x			1
Ambient Cond	RDX/Perc	NA	NA	NA	NA	x			2

1 Scenario 15b featured two wells in place of the middle extraction well J3EW0002, arranged perpendicular to the long-axis of the plume.
2 Scenario 19b featured a four-well axial arrangement.
3 Scenario 20b featured a five-well axial arrangement.
4 Scenario 23b featured a five-well axial arrangement.
* Scenario 22 also included a deep extraction well pumping at 50 gpm targeting the deep portion of the perchlorate plume.

* alphabetic characters following scenario numbers correspond to reinjection configurations, as follows:
'a' 4 total reinjection wells, two along Wood Road and two along Jefferson Road.
'b' 2 or 4 infiltration trenches, depending on the total flow rate and number of wells in the simulation.
'c' 2 infiltration trenches along Jefferson Road.
'd' reinjection stress removed from area.
'e' Uses 4 infiltration trenches, similar to a 'b' scenario, with infiltration from EW2 shifted to Wood Road.
'g' Similar to 'e' configuration, with trenches along Wood and Jefferson Roads moved closer to the plume boundary.

gpm = gallons per minute
RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine
Perc = perchlorate

Table 5-6

J-2 North Groundwater RRA Plan

Scenario 25g_u Extraction Well and Infiltration Trench Locations and Flow Rates

	Easting (ft)	Northing (ft)	Discharge (gpm)	Top of Screen Elevation (ft)	Bottom of Screen Elevation (ft)
Extraction Wells					
J2EW0001	869063.00	260616.00	-75.00	-5.00	-60.00
J2EW0002	869563.97	262138.08	-175.00	-20.00	-55.00
J2EW0003	870051.40	264038.76	-125.00	-20.00	-50.00
Infiltration Trenches					
J2T1b_begin	870410.00	260478.00	17.86	68.40	63.40
J2T1b_end	870290.00	260568.00	17.86	68.40	63.40
J2T2b_begin	868442.00	261439.00	17.86	68.00	63.00
J2T2b_end	868420.00	261449.00	17.86	68.00	63.00
J2T3b_begin	869535.00	263774.00	8.93	66.00	60.50
J2T3b_end	869406.00	263851.00	8.93	66.00	60.50
J2T4b_begin	870514.00	263186.00	8.93	66.30	61.20
J2T4b_end	870537.00	263177.00	8.93	66.30	61.20

ft = feet
gpm = gallons per minute

Table 5-7
J-2 North Groundwater RRA Plan
Summary Statistics for Selected Inorganic and Field Measurement Parameters

Analyte	Units	Minimum	Minimum Detected Result	Maximum Detected Result	Mean (including nondetects)	Mean (excluding nondetects)	Number of Detections	Number of Non Detections	Number of Usable Samples
ALKALINITY, BICARBONATE (AS CACO3)	mg/L	ND	3	31	9.2	9.4	97	2	99
ALKALINITY, CARBONATE (AS CACO3)	mg/L	ND	0	0	0	0	0	99	99
ALKALINITY, TOTAL (AS CACO3)	mg/L	ND	3	31	9.2	9.4	97	2	99
CHLORIDE (AS CL)	mg/L	5.3	5.3	15.5	8.97	8.97	97	0	97
HARDNESS (AS CACO3)	mg/L	ND	9	11	0.32	10	4	122	126
NITROGEN, AMMONIA (AS N)	mg/L	ND	0.02	0.14	0.0257	0.047	43	56	99
NITROGEN, NITRATE-NITRITE	mg/L	ND	0.01	1.9	0.084	0.1	83	16	99
PHOSPHORUS, TOTAL PO4 (AS PO4)	mg/L	ND	0.01	0.37	0.024	0.036	61	37	98
SULFATE (AS SO4)	mg/L	2.2	2.2	22.9	6.4	6.4	97	0	97
TOTAL ORGANIC CARBON	mg/L	ND	0.5	3	0.2	0.9	26	73	99
IRON (TOTAL)	µg/L	ND	28.6	5120	204	648	37	85	122
MANGANESE (TOTAL)	µg/L	ND	0.66	324	60.1	66	111	11	122
pH	su	4.22	4.22	8.65	6.25	6.25	286	0	286
TEMPERATURE	°C	5.68	5.68	16.42	10.89	10.89	304	0	304
DISSOLVED OXYGEN	mg/L	0.07	0.07	22.95	10.71	10.71	302	0	302
OXIDATION-REDUCTION POTENTIAL	mV	-145.2	-145.2	488.8	201.3	201.3	301	0	301
SPECIFIC CONDUCTANCE	µS/cm	5	5	191	62	62	285	0	285
TURBIDITY	ntu	-7	-7	335.2	8.9	8.9	302	0	302

Note: The MEAN is calculated using one-half the Detection Limit as the value for samples that did not have a detectable concentration.

Date range: 07/31/97 - 11/23/04, Matrix: Groundwater.

Outliers were determined and removed from data set for pH, temperture, dissolved oxygen, oxidation reduction potential, specific conductance and turbidity by Q-test.

°C = degrees Celsius
mg/L = milligrams per liter
mV = millivolts
ND = nondetect
ntu = nephelometric turbidity units
su = standard units
µS/cm = microSiemens per centimeter

Table 5-8
J-2 North Groundwater RRA Plan
Analytical Results Used for Assessment of System Fouling Pre-treatment Requirements

MW-300M2 Sampled 7 December 2004		
	Pre-Purge	**Post-Purge***
Phenolphthalein Alkalinity (as $CaCO_3$) (mg/L)	0	0
Total Alkalinity (as $CaCO_3$) (mg/L)	0	4
Hydroxide Alkalinity (mg/L)	0	0
Carbonate Alkalinity (mg/L)	0	0
Bicarbonate Alkalinity (mg/L)	0	4
pH	6.3	6.6
Chlorides (as Cl) (mg/L)	17.5	15.8
Total Dissolved Solids (mg/L)	45	44
Conductivity (micromhos)	58	57
Total Hardness (as $CaCO_3$) (mg/L)	0	4
Carbonate Hardness (mg/L)	0	4
Non Carbonate Hardness (mg/L)	0	0
Calcium (as $CaCO_3$) (mg/L)	0	0
Magnesium (as $CaCO_3$) (mg/L)	0	4
Sodium (as Na) (mg/L)	14.1	10.4
Potassium (as K) (mg/L)	0.1	0.1
Phosphate (as PO_4) (mg/L)	0.2	0.2
Dissolved Iron (as Fe^{2+}) (mg/L)	0	0
Suspended Iron (as Fe^{3+}) (mg/L)	0.1	0.1
Iron Total (as Fe) (mg/L)	0.1	0.1
Iron (resuspended) (mg/L)	0.1	0.2
Copper (as Cu) (mg/L)	0	0
Tannin/Lignin (mg/L)	0	0
Nitrate (as N) (mg/L)	0.3	0.1
Sulfate (as SO_4) (mg/L)	2.8	3.4
Silica (as SiO_2) (mg/L)	9.3	10.1
Manganese (as Mn) (mg/L)	0	0
Saturation Index	-11.8	-7.9
Chlorine (as Cl) (mg/L)	0	0
Oxidation-Reduction Potential (mV)	225	233
Plate Count (colonies/ml)	51	12
Sulfate Reducing Bacteria	Negative	Negative
Anaerobic Growth (percent)	10	< 10
ATP (cells/ml)	<1000	120000

*well was purged for three hours prior to sampling.

Elevation of MW-300M2 is located between -25.85 and -35.85 feet msl.

mg/L = milligrams per liter

ml = milliliters

mV = millivolts